California Energy Commission

STAFF REPORT

Productivity and Status of Wind Generation in California

2014 Through 2016

California Energy Commission

Gavin Newsom, Governor

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ABSTRACT

This document was prepared to analyze and describe data collected through the Wind Performance Reporting System of the California Energy Commission. The report provides information to support the development of state energy policy, including growth in the renewable energy portfolio, greenhouse gas reduction, planning for natural gas generators, and reduction of water use.

The data cover wind generation and energy purchases from in-state wind projects with a nameplate capacity of at least 1 megawatt (MW) from 2014 through 2016. Analyses on capacities, energy produced, capacity factors, turbine numbers, generation operators, specific power, and specific energy are provided within the report. The report also examines differences among the Wind Resource Areas of California.

During this three-year period, the net energy produced averaged 13,000 gigawatt-hours per year with a final capacity of 5,644 MW and a combined capacity factor of 26 percent. Wind generation peaked in the second quarter of each year. The Tehachapi Wind Resource Area was the largest of the six established wind resource areas in the state. Statewide, the number of turbines decreased, especially in the Altamont area, while the average capacity per turbine increased. Most wind energy was purchased by investor-owned utilities.

Keywords: California wind generation, capacity, capacity factor, turbine numbers, specific power, specific energy, wind resource areas, energy purchases, electricity consumption, generation trends, regional variations, wind generation status

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Background

Wind generation in California makes up about one-quarter of renewable electric generation in the state by energy and by capacity in 2016. Wind projects extend from Imperial County in the south to Shasta County in the north. Detailed knowledge of wind projects, energy produced, and energy purchases provides part of the foundation for growth toward higher levels of clean energy for the state. Wind generation relates to several policy areas identified in the *2016 Integrated Energy Policy Report Update* and the final *2017 Integrated Energy Policy Report*. Among those stated policy goals are greenhouse gas reductions, transmission planning, imports of renewable energy, grid reliability, characteristics of natural gas generators, water use, potential offshore wind generation, and repowering. Information to support these policy goals and better understand wind generation is available from data obtained through the California Energy Commission's Wind Performance Reporting System. This data set includes projects available to generate and sell electricity but not projects in earlier stages of development.

Purpose

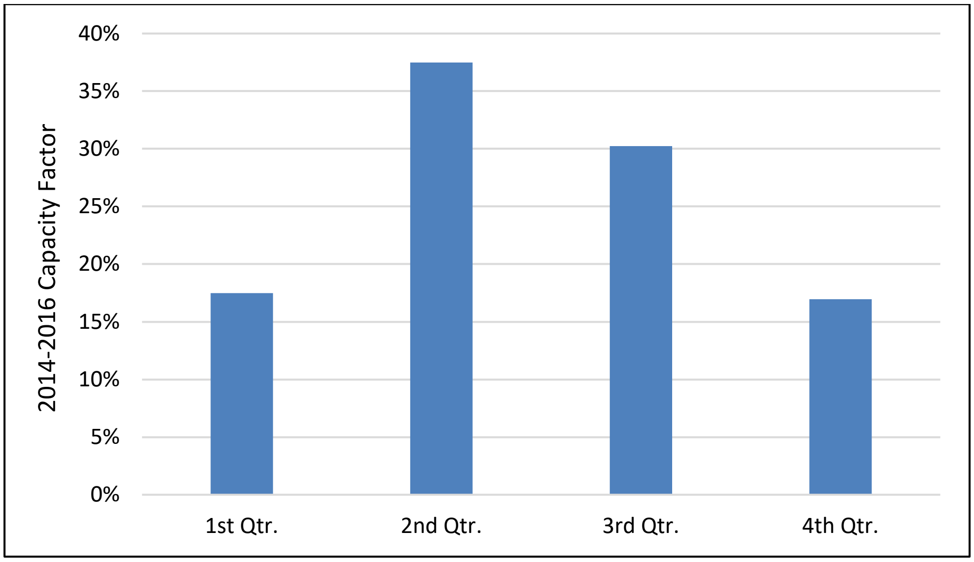
This report summarizes and analyzes the data and information obtained by the Energy Commission through the Wind Performance Reporting System. These are data primarily on generators and generation, with some energy purchase data. They describe the three-year period of 2014 through 2016, which is the first three years of comprehensive and detailed data collection since the Wind Performance Reporting System was modernized. Wind data are collected from California project operators and wind energy purchasers from in-state projects of at least 1 megawatt (MW) in nameplate capacity.

Take-Away Messages

- Wind generation projects in California produced an average of almost 13,000 gigawatt-hours per year from 2014 through 2016.
- Wind projects provided the energy used in about 1.9 million California households, with the average household consuming about 7 megawatt-hours per year.
- Statewide capacity decreased over the period, ending at 5,644 MW available to generate at the end of 2016.
- The number of turbines available decreased while the average capacity per turbine increased.
- Wind generators had a net capacity factor of 26 percent over the three-year period.
- Annual capacity factors for quarter two for the whole fleet ranged from 36 percent to 40 percent, varying by year.

- Wind capacity factors over the three-year period were highest in the second calendar quarter at 37 percent and lowest in the fourth quarter at 17 percent, as shown in **Figure ES-1**.

Figure ES-1: Net Capacity Factors by Quarter Over 2014 Through 2016



Source: WPRS data set of the California Energy Commission

- Among areas of the state, generation was highest in the Tehachapi Wind Resource Area in Kern County, followed by the Solano Wind Resource Area in Solano County, the San Gorgonio area in Riverside County, and the Altamont area in Alameda County.
- Average statewide electricity consumption peaks in August and reaches a low in February. Wind generation peaks in June, with a minimum in January.
- Most wind energy was purchased by investor-owned utilities, followed by publicly owned utilities, energy service providers, and community choice aggregators. Community choice aggregators and onsite users purchased a small but growing share of wind energy.

CHAPTER 1: Introduction

Higher renewable energy portfolio goals in the law for the coming years suggest that wind generation will provide increasing support to meet state demands for clean energy. California in-state wind generation makes up 24 percent of the renewable energy and 27 percent of the renewable capacity in the state as of the end of 2016 (California Energy Commission, 2018). The state houses a diverse array of wind projects across nearly its entire length, with a wide range in project size, characteristics, and output. Wind projects extend from the forested northern end of the state to the desert areas in the south. The largest capacity wind project in the state, Ocotillo Express in Imperial County, is depicted in **Figure 1.** This photograph shows 4 of the 112 turbines installed.

Figure 1: A Portion of the Ocotillo Express Project

Source: Sergio Gonsales, Pattern Energy

Information on the productivity and status of wind generation in California provides part of the foundation to evaluate policy issues as the state makes the transition to cleaner energy sources. Planning for higher renewable energy goals requires detailed knowledge of present generation projects, the energy they produce, characteristics of the generators, and wind energy purchases.

Data Sources

Data to support policy on wind energy are available from the Wind Performance Reporting System (WPRS) of the Energy Commission. This system is used by generation operators and wind energy purchasers to report data and by staff to collect data since re-initiation of the system in 2014. This report describes wind energy in the state over the first three years of the WPRS, 2014 through 2016, focused primarily on energy generation. The WPRS collects data required by the California Code of Regulations. Most operators and purchasers use online reporting, which includes data quality controls in the software. The online WPRS data reporting system promotes collaboration by staff of operators and energy purchasers in different offices.

Analysis in this report uses reported, public data, supplemented by related data concerning wind power in California. Analysis focuses on production at the turbine group level and larger perspectives, such as the project, region, utility territory, and state levels. A turbine group comprises turbines within one project of the same make, model, and capacity. Wind projects within the state contained 179 turbine groups in 110 projects at the end of 2016. The groups had a median of 24 turbines per group, and the largest group comprised 460 turbines.

Data Quality

Staff reviewed the reported data to identify inconsistencies and worked with reporters on revisions where needed. Supplemental data were used when reported data did not give a complete picture. As a quality check, staff analyzed the WPRS data set for 2016, the most recent year of complete data, to check whether variables that were expected to influence energy production were significant. This analysis was done using a linear regression procedure to identify which variables significantly affected energy production for turbine groups. Energy production values were reported data. The values of potentially significant variables were from data collected by the Energy Commission and parameters determined in earlier studies sponsored by the Energy Commission (Bailey, 2006; California Energy Commission, 1980; and TrueWind Solutions, LLC, 2002). The result of this analysis confirmed the overall high quality of the data set.

Related Energy Policies

The Energy Commission identifies several policy areas affected by wind generation in its *2017 Integrated Energy Policy Report* (*2017 IEPR*). These begin with increasing the resiliency of the electricity sector. Reducing greenhouse gases depends on increasing additions of new renewable resources, and the *2017 IEPR* states that most of these sources will come from wind and solar generation. The report notes the opportunity to develop renewable generation in regions with operating profiles to complement the operational needs of the grid. Evaluation of the tradeoffs between external and in-state resources depends on a complete understanding of in-state generation. A variety of transmission projects are being considered to make use of out-of-state generation. The *2017 IEPR* includes references to wind generation projects in New Mexico and Wyoming, with possible connection points in Utah, Nevada, and Arizona.

Other policy issues that knowledge of wind generation can inform are stated in the *2016 IEPR Update*. The growth in wind and solar generation can bring new responsibilities for grid operators as they maintain reliability while adjusting to variations in renewable output. Wind and solar generators are sometimes in remote areas throughout the western grid, and the need for stronger interconnections across the grid is leading California to pursue more regional interconnection with other western states. Growth in renewables is also affecting the natural gas fleet due to the need for more responsive gas generation. Water use has decreased with the addition of renewable resources. Wind plants do not use water or a steam cycle, as conventional generators do. Another consideration regarding the wind fleet is the related effect on wildlife, particularly birds. Repowering wind facilities can reduce impacts to birds. The state is decreasing its reliance on coal generation, and renewable sources are increasing to make up some of the electricity required by consumers. Each of these policy considerations in the *2017 IEPR* and *2016 IEPR Update* benefits from a better understanding of the productivity and status of existing wind projects in the state.

Implementing Senate Bill 100 (De León, Chapter 312, Statutes of 2018) also supports the need for an understanding of wind energy in California. This bill increases the Renewables Portfolio Standard targets for future years. The bill accelerates renewables targets and establishes higher targets, including 60 percent by 2030 and 100 percent renewable and zero-carbon resources by 2045. In addition, a set of benefits to California is intended by the bill. These benefits include displacing fossil fuel consumption, adding new generating plants, reducing air pollution, reducing greenhouse gas emissions, promoting stable rates for electricity, meeting the need for a diversified and balanced portfolio, and providing voltage support. Achieving these benefits can be informed through an understanding of wind energy in the state.

Repowering, that is, replacing older equipment with newer, more efficient wind turbines, is another policy area that can be informed by detailed knowledge of existing wind generation. By comparing historical generation to an estimate of repowered production, the value of repowering could be understood. Repowering ultimately depends on project economics. Owners of projects need to see a financial benefit to repowering before they replace existing turbines (Christenson, 2014). Repowering goals may need further policy support or programs before they can be realized with current economics.

Offshore Wind Power

Offshore wind power, an opportunity identified in the *IEPR*, is an active planning area, and the Energy Commission has opened Docket #17-MISC-01.[1] The Energy Commission is working with the federal Bureau of Ocean Energy Management to identify potential lease areas for offshore wind development. These areas include one near Eureka and two near Morro Bay. The bureau has published a call for information and nominations for companies interested in commercial energy leases within the proposed areas. The bureau has received a request for a commercial lease near Morro Bay from Trident Winds. The Redwood Coast Energy Authority is also pursuing an offshore wind project. The authority has formed a partnership to develop a project offshore of Humboldt County, and it submitted an application for a commercial lease to the bureau.

1 Docket accessible at [http://www.energy.ca.gov/renewables/offshore_energy/.](http://www.energy.ca.gov/renewables/offshore_energy/)

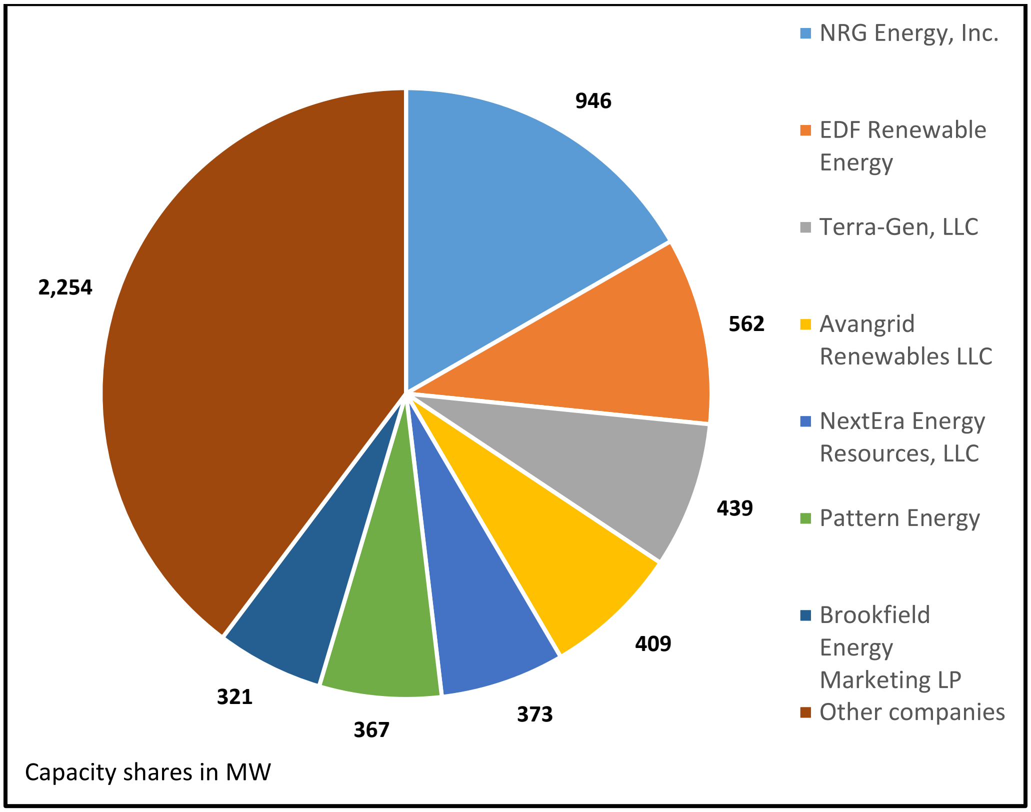
As the technology to capture the offshore wind resource continues to develop worldwide, large wind resources off the California coast are becoming available at decreasing prices. Equipment, practices, and installation methods are developed internationally, and the knowledge is transferred to each country that begins to invest. Development of this energy source in California would benefit from the knowledge accumulated in Europe and Asia over the last two decades. Offshore contract prices in Europe have fallen much faster in recent years than industry observers expected (*Financial Times*, 2017). Offshore resources will be compared to existing onshore resources and operating onshore wind projects.

Current discussions of offshore wind in California often focus on deep-water foundation systems. Although there are wind resources within shallow water depths of the coast, use of much of the resource will require adapting to deeper water. Deep-water mooring systems can be used to site projects beyond the visible distance from beaches, thus minimizing the visual impact. Public acceptance of renewable energy projects is complex, multi-factored, and difficult to predict. It is influenced by at least these types of factors: economic stakes in project costs and benefits; environmental values (such as opinions about greenhouse gas emissions, wildlife, and visual factors); community experience with energy projects; and perceptions about participation in planning and decision-making of government and project developers.

CHAPTER 2:
Statewide Capacity, Capacity Factors, and Generation

California has 113 in-state wind projects operated by 45 companies at the end of 2016. The market in wind generation projects is dynamic, with projects changing both operators and owners often. Operating companies range from affiliates of multinational energy companies with staff in many cities in the United States and Canada to small companies with staff at project sites. Companies operating the largest shares of capacity in 2016 are shown in in **Figure 2**. Smaller capacity fractions are grouped in the final slice of the pie chart. From 2014 through 2016, operators staying in the top ranks included Terra-Gen (Operating Company), EDF Renewable Energy, Brookfield Energy Marketing, Pattern Energy, and BHE Renewables.

Figure 2: Operating Companies With Highest Capacity (MW) in 2016



Source: WPRS data set of the California Energy Commission

California in-state wind generators produced an average of almost 13,000 GWh net energy per year during the period of 2014 through 2016, as shown in **Table 1**. In 2016, the average household in the state consumed 7.02 MWh.[2] The in-state wind projects produced as much net energy as 1.9 million households consumed.

Table 1: 2014-2016 Generation, Capacity, and Capacity Factors by Year

Year	Net GWh	End-of-Year Capacity (MW)	Annual Net Capacity Factor (Percent)	Number of Turbines at End of Year
2014	13,074	5,865	26	11,500
2015	12,191	5,998	24	10,927
2016	13,499	5,644	27	7,400
2014-16 period	38,763		26	
3- year average	12,921			

Source: WPRS data set of the California Energy Commission

Statewide wind production was highest in 2016 and lowest in 2015, with the highest capacity factor (CF) in 2016. The CF measures how closely a project comes to reaching the maximum production possible based on the electrical capacity of the generator. It is the ratio of the energy produced to what could have been produced if the project had run at nameplate capacity for the entire period. A small number of lower capacity projects are rerated by the operator, and the revised values are used in the calculations. The CF over the full, three-year period was 26 percent. The statewide average CF varied over 3 percentage points during the three years due to natural fluctuations in wind speed from year to year.

Lower production occurred in 2015 as California and other states experienced low wind speeds in the first half of that year. In-state wind generation made up 7 percent of electric energy and 7 percent of capacity in California in 2016.

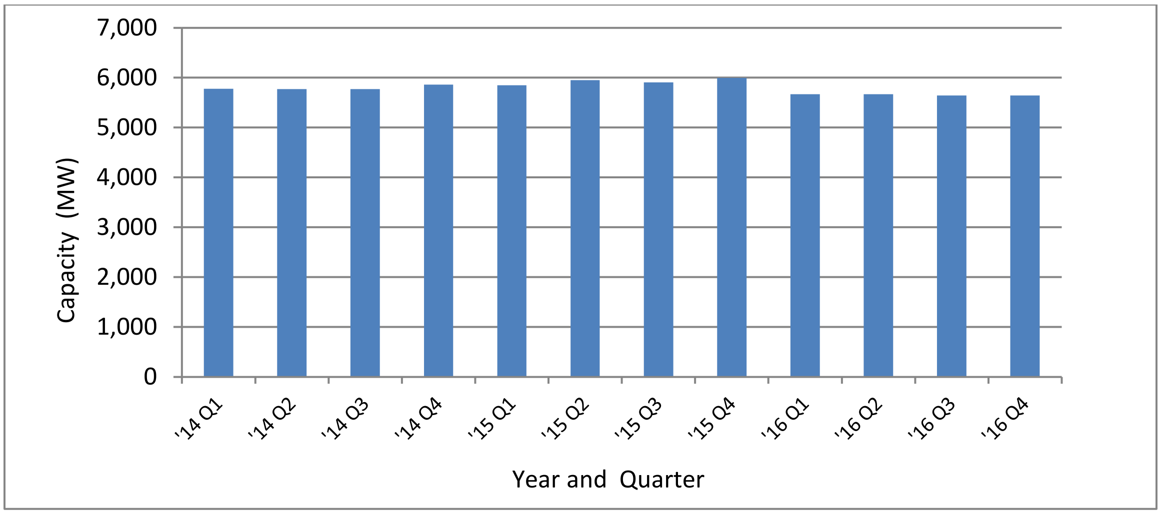
Net annual CF listed in **Table 1** take into account the changes in capacity with each calendar quarter, with the fourth quarter capacities shown in the table. CFs are influenced by the mix of turbines with older technology and recent projects with newer technology. Annual factors include the variations among seasons, with higher production in the second and third quarters and lower in the first and fourth. Individual plants in the high season can reach a CF during a month that is three times higher than a statewide annual value.

2 Chris Kavalec, California Energy Commission, Demand Analysis Office, in discussion with the author, April 9, 2018.

Statewide Capacity

Statewide nameplate capacity was relatively stable with a slight decrease over the period as depicted in **Figure 3**. Evolution of the turbine fleet is ongoing in California, and some older projects have retired turbines, either through planning or through attrition of equipment that is no longer economical to maintain. However, the net result of retirements, attrition, equipment installation, and changing ownership is that statewide capacity changes averaged under 1 percent each quarter. Over the three-year period, the number of turbines in operation decreased, while the average capacity per turbine increased from 0.5 MW to 0.8 MW, as the turbine fleet evolved toward larger-capacity machines.

Figure 3: Capacity by Quarter



Source: WPRS data set of the California Energy Commission

For most wind projects in the state, operators report the nameplate capacity. Some of the smaller, newer projects report a derated capacity to qualify for energy sales within the Net Energy Metering program. These smaller projects, such as the Anheuser-Busch factory in Fairfield, typically serve an onsite end user directly. The effect of lowering the reported nameplate capacity increases the CF, but, as these smaller projects are near the lower threshold of WPRS reporting, the result has little effect on the regional or statewide CF calculations.

The 2014-through-2016 period saw changes in capacity and numbers of turbines due to equipment changes, decommissioning, and new installations. Over the period, 8 projects began operation, 20 were decommissioned, and 13 others had capacity changes. The fourth quarter of 2015 saw a significant decrease in the number of turbines. A single project is defined by state regulation and reporting guidelines as comprising at least one turbine which sells electricity to another party. Projects in planning, financing, engineering, or construction that have not started selling are not included. New projects included four small projects and four large projects. An example of a large project is the Rising Tree Wind Farm III project of 99 MW in Kern County.

WPRS classifies large projects as those rated at 10 MW or more in nameplate capacity; large projects report monthly data. Small projects are at least 1 MW but under 10 MW, and these report quarterly data. Some small projects serve adjacent end users who contract to buy the energy produced. These projects represent a newer type of one-to-two turbine operation, which produces and uses the energy; the end users are industrial, commercial, or agricultural operations.

One example of a newly developed small project is at Taylor Farms near Gonzales in the Salinas Valley, shown in **Figure 4,** comprising a 1 MW turbine. This project was developed by Foundation Windpower, LLC. The company has been successful at finding sites where good wind resources can be matched with commercial and industrial energy users in locations of good wind resources and installing wind generators onsite. The business model includes contracting with the energy customer to sell the electricity, often at rates below those available from the utility. The model makes use of the net-energy-metering tariff, enabling the consumer to sell the excess wind energy onto the grid when demand is less than the output of the turbine. The company finances, builds, and maintains the project at its own expense. The energy user may pay internal legal or closing costs. The end user is often an energy-intensive enterprise, such as a food processor, which has a strong interest in reducing its energy costs.

Figure 4: Recent Onsite User Project in Salinas Valley

Source: Steve Sherr, Foundation Windpower

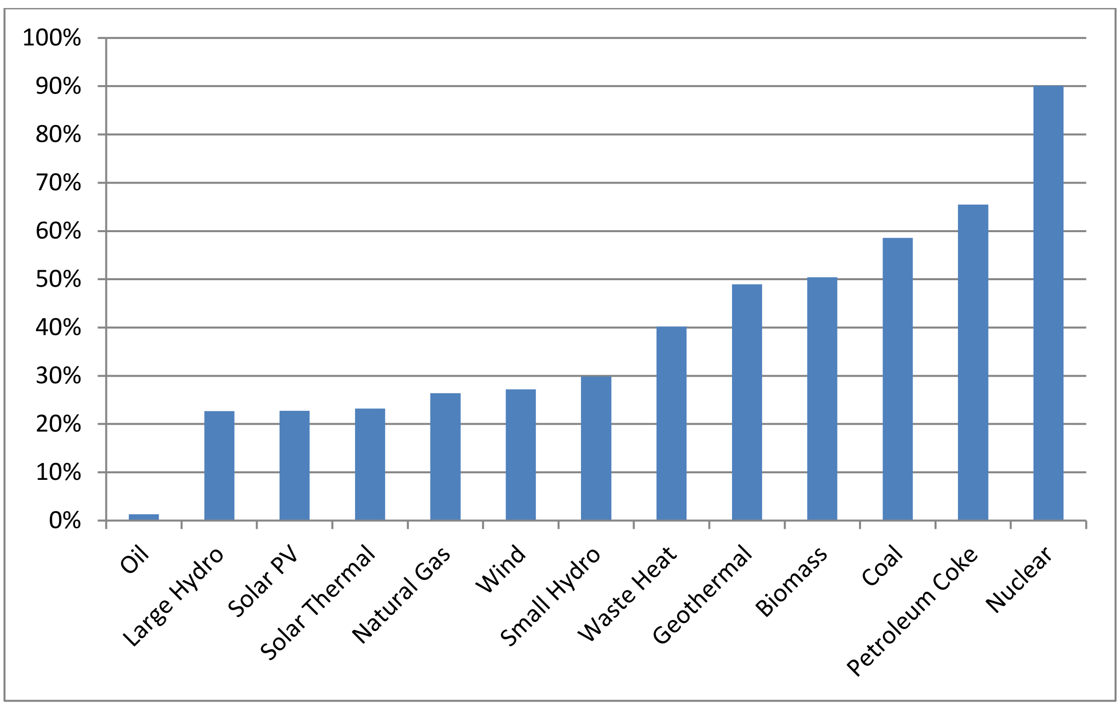
Statewide Capacity Factors

Capacity factors in 2016 for in-state electric generation are shown in **Figure 5** by fuel type. The CF of wind was just above natural gas, at 26 percent, and below small hydro, at 30 percent. Solar thermal and photovoltaic were each 23 percent. In comparison to other in-state sources of electricity in 2016, the wind CF was near the middle (California

Energy Commission, 2018). CFs of other fuel types ranged from 1 percent for oil-fired generators to 90 percent for nuclear.

Nationally, wind generation is often compared to natural gas generation as the most direct competitor for electricity supply. Natural gas generators are often ramped up or down to complement wind and other variable renewable generators. In many parts of the United States, natural gas and wind are competitors to be the cheapest source of generation. Recent state policy direction has the state moving further away from natural gas with a shift toward cleaner sources of electricity. Cost analysis indicates that the levelized cost of energy from new wind generation is lower than that from new natural gas plants (Energy Information Administration, 2018). Analysis of the costs of electricity in California for 2030 predicts that onshore wind generators will be able to deliver energy at about one-fourth the cost of fossil fuel generators without externality costs or one-fifth with fossil fuel externalities (Jacobson et al., 2014).

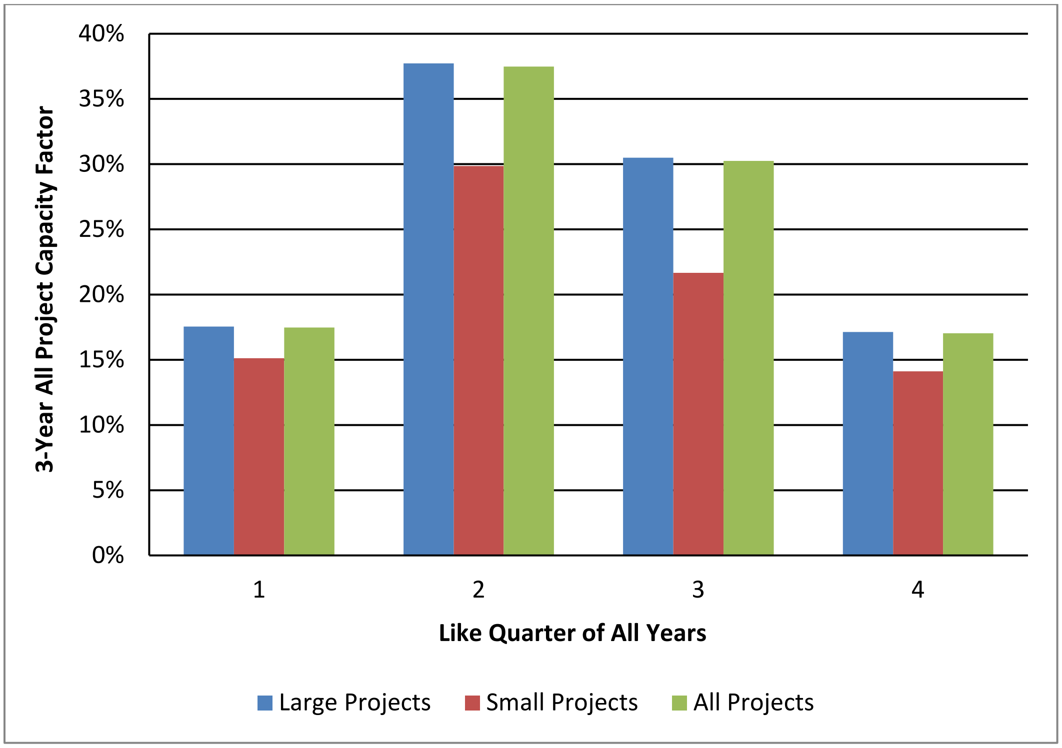
Figure 5: 2016 Capacity Factors of In-State Electric Generation



Source: QFER data set of the California Energy Commission

Average net generation CF from in-state wind projects is shown in several graphs that depict projects by quarter and month. **Figure 6** shows the factors calculated for the full three-year period by like calendar quarter (for example, the first quarters of all three years) and by project size. These factors account for the changes in capacity from quarter to quarter. A few observations can be made about the data. In every quarter, small project factors are lower than those of large project factors and lower than factors for all projects. Factors of the large projects are slightly higher than factors of the whole fleet. Quarter 2 is higher than other quarters for every size range, and Quarter 3 is second highest. Quarters 1 and 4 are much lower.

Figure 6: Full Period Capacity Factors by Like Quarter and Project Size

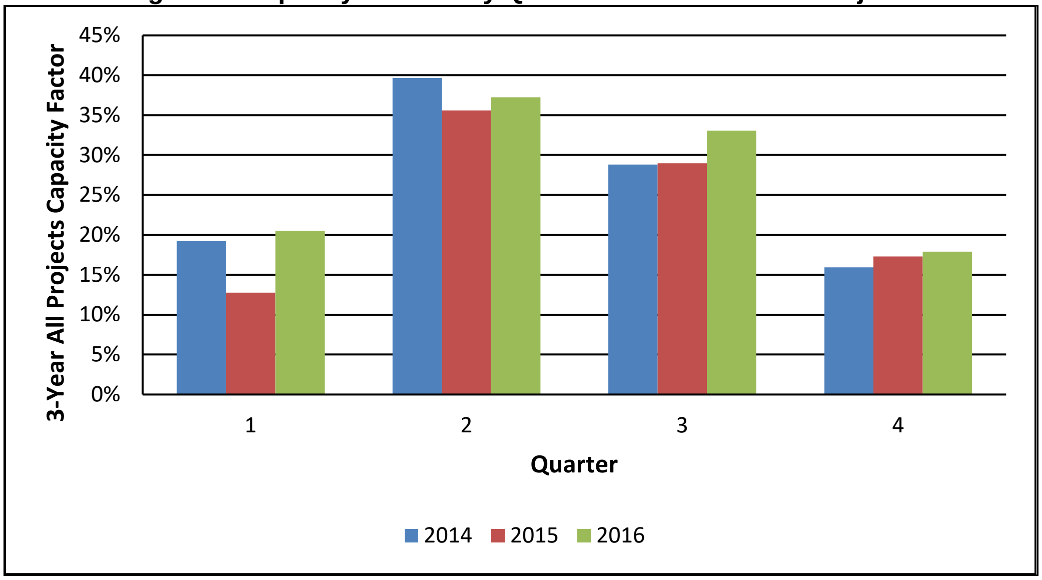


Source: WPRS data set of the California Energy Commission

CFs include the capacity of all turbines that are available to operate during a period. Available turbines may not operate for reasons including county restrictions for environmental mitigation, the operator's economic reasons, and curtailment by a utility for maintenance of its equipment.

The data can also be examined year by year to show the variability between years. **Figure 7** depicts CF for all projects by quarter over the three years. The factors peak in Quarter 2 each year at 35 to 40 percent and are lowest in Quarter 1 or 4, varying by year. Low CF values in the first part of 2015 are evident. These values reflect unusual low wind resource conditions that are explained further by the low wind speeds described below under Wind Speeds and Variations.

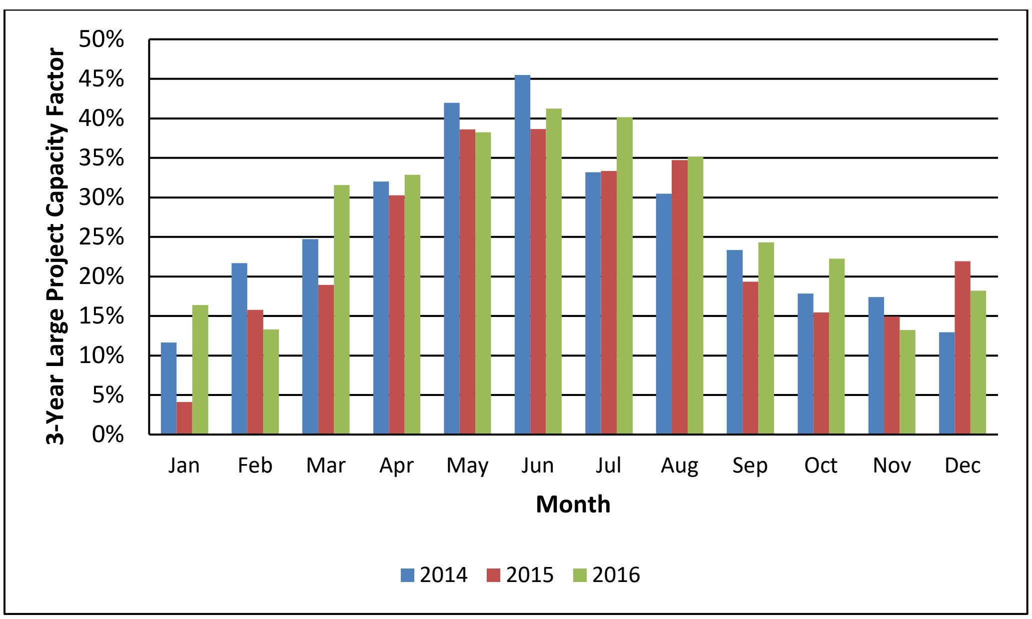
Figure 7: Capacity Factors by Quarter and Year for All Projects



Source: WPRS data set of the California Energy Commission

Projects of at least 10 MW capacity report monthly data, with the CF profiles shown in **Figure 8**. The monthly variations in energy production from year to year are evident, as is the overall pattern of peaking in the summer months. Factors are highest in June of each year. Lowest factors occur between November and January, also depending on the year. The wide range of the group is visible, from less than 5 percent in January 2015 to more than 45 percent in June 2014.

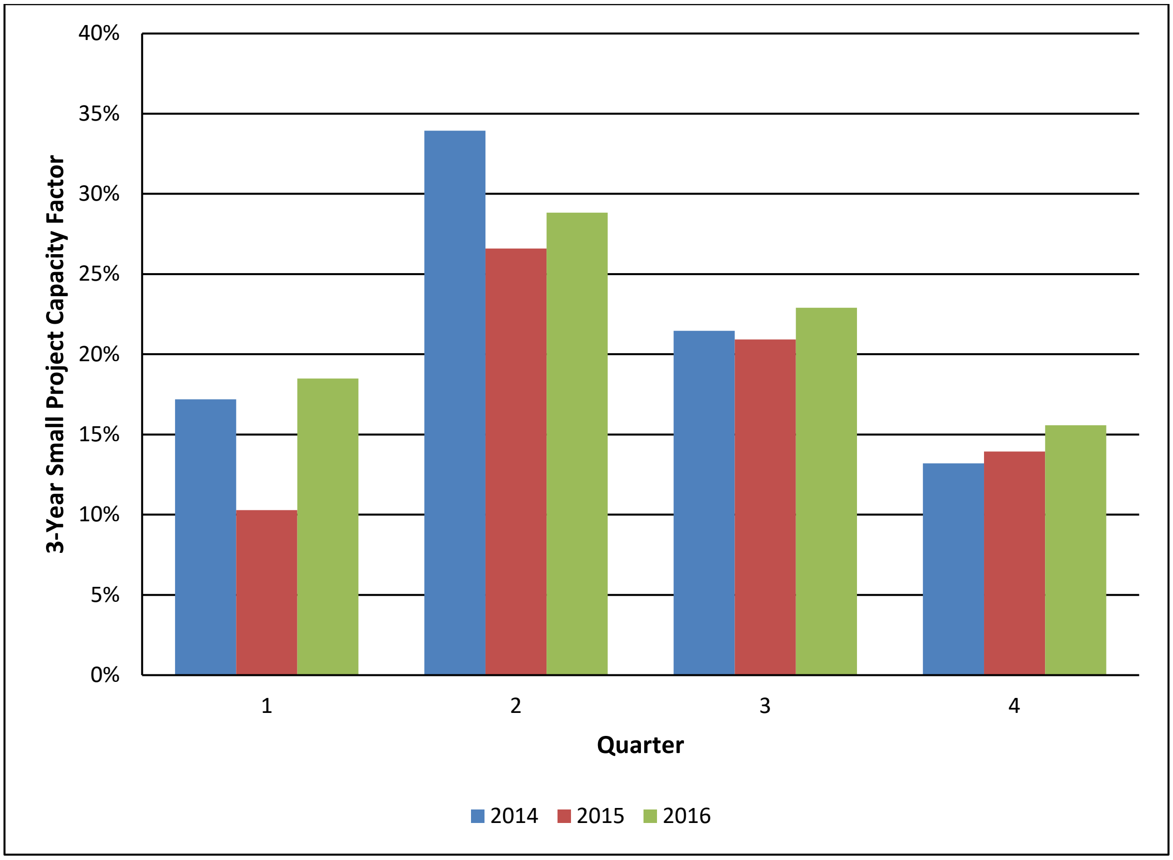
Figure 8: Capacity Factors by Month and Year for Large Projects (≥10 MW)



Source: WPRS data set of the California Energy Commission

Projects under 10 MW capacity show similar patterns, as illustrated in **Figure 9**. These projects reached a high of 34 percent in the second quarter of 2014 and a low of 10 percent in the first quarter of 2015. In each of the graphs of 2014 through 2016 CFs, the overall shape of the profile is similar, while the particular quarters or months show smaller differences from one year to another.

Figure 9: Capacity Factors by Quarter and Year for Small Projects (1 to <10 MW)



Source: WPRS data set of the California Energy Commission

Seasonal and Interannual Variability in Capacity Factors

Net quarterly CFs varied from 16 to 40 percent over the three-year period. Based on the same quarters across the full period, CFs ranged from 17 percent to 37 percent by quarter. Maximum values occurred in the second quarter of each year. These values reflect the lower wind speeds in the state during 2015 and stronger winds in 2016. The CFs by year ranged from 24 percent to 27 percent, as listed in **Table 2**.

Table 2: Net Generation Capacity Factors by Quarter and Year for All Projects

Year	Qtr. 1	Qtr. 2	Qtr. 3	Qtr. 4	Annualized
2014	19%	40%	29%	16%	26%
2015	13%	36%	29%	17%	24%
2016	21%	37%	33%	18%	27%
Over Same Quarters	17%	37%	30%	17%	26%

Source: WPRS data set of the California Energy Commission

Variations between the years were largest in Quarter 1 and smallest in Quarter 4. Quarter 1 includes January through March, when the land is heating from increased solar radiation. Uneven heating can produce high variability in winds. In Quarter 2 (April through June), high solar radiation can induce large temperature differences between land and ocean areas or between mountain and valley areas. These differences can cause strong, sustained airflow from one area to another, leading to high wind power. Stronger winds (up to a maximum) and longer-duration winds can lead to higher energy production.

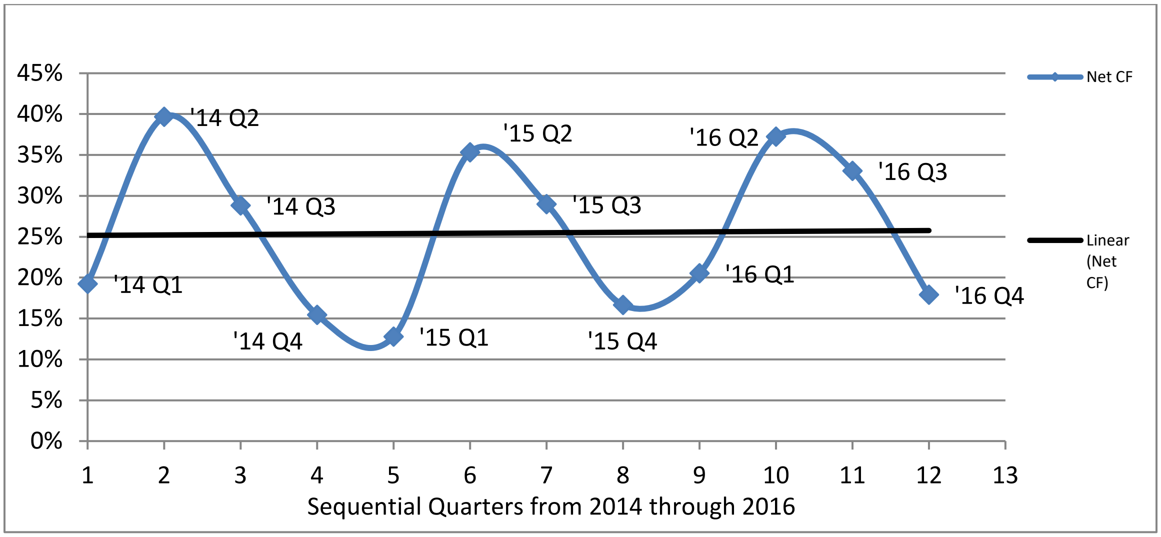
Seasonally migrating, semi-permanent pressure systems may also play a role in California's wind. In the summertime, a high-pressure cell lies off the coast of California, with low pressure generally present inland due to warmer temperatures. The difference creates a pressure gradient, with a northwesterly wind flowing into the state. The strength of these systems varies from year to year, with steeper gradients leading to higher winds. In the winter, low land temperature causes high pressure to form inland, while the nearest semi-permanent low pressure cell is usually thousands of miles away, west of the Gulf of Alaska. The lack of a steep pressure gradient in this case might depress winter wind speeds.

Natural variations are present in energy sources that depend on cycles in weather or other natural phenomena. Variations in the solar resource in the hourly, daily, and seasonal scales affect production from solar generators directly (and they affect wind speeds indirectly). Electric system operators monitor and adjust to these natural variations continually as they manage the balance of energy generation and demand on the grid.

Cyclical Nature of Capacity Factors

CFs are cyclical, with a slight upward trend over time, reflecting the cyclical wind speeds over a year. The trend is likely a result of the updating of turbine vintages as older turbines are retired. Operators generally keep older turbines in service as long as there is a contract for sale of the energy produced and they require only low-cost maintenance. **Figure 10** shows the factors for the three years in 12 quarters, with a trend line. Apparent here are the peak times in Quarter 2 of each cycle and the minimum times in Quarter 1 or 4. The high generation in Quarter 2 of 2014 and the low generation in Quarter 1 of 2015 are also visible.

Figure 10: Capacity Factor Cycles



Source: WPRS data set of the California Energy Commission

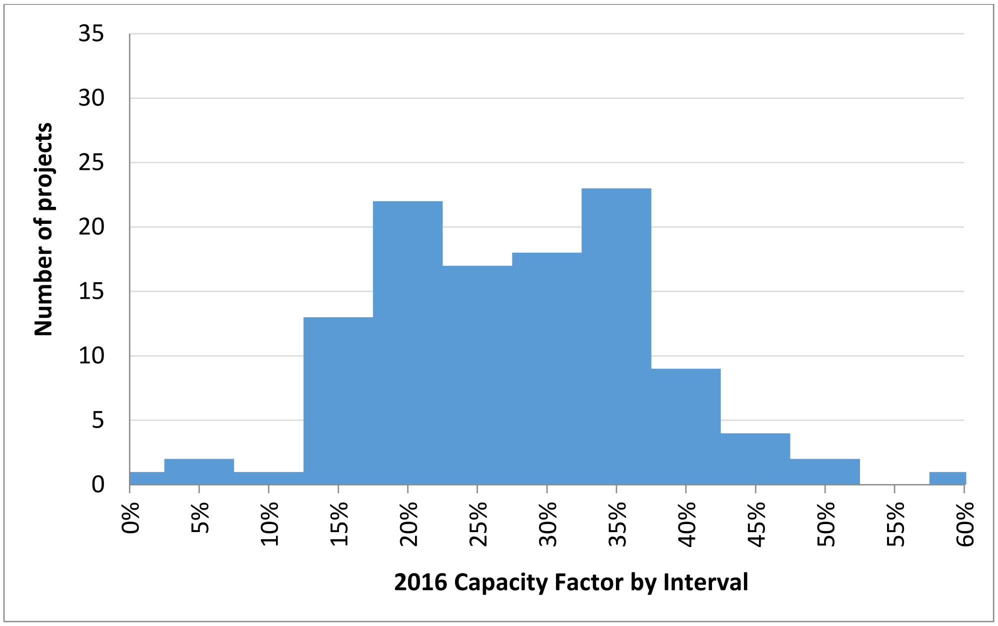
Individual Project Capacity Factors

The graphs and data presented above describe patterns and trends in CF over groups of projects. However, individual projects show a wider range of CFs than large groups. A "project" is a defined in regulation as group of wind turbines totaling at least 1 MW nameplate capacity, the electricity from which is sold to another party. The turbines in a project are normally located close together, often in a row or parallel rows. A common arrangement is to site the rows perpendicular to the dominant wind direction. This arrangement minimizes the effect of one turbine on another during productive times. Projects exhibit annual net CFs ranging from 0 percent to 56 percent annually.

Factors at single projects for shorter periods can be much higher during the summer, ranging up to almost 80 percent for particular months. The wide range in these figures encapsulates the great variation in productivity among operating wind projects in California. The CF is the result of many factors that affect realized production, including siting, project design and engineering, management and operation, contractual terms, market opportunities, and external limits on generation like those by a county or the electric system operator.

The distribution of individual project capacity factors for 2016 is graphed in **Figure 11,** in intervals of five percentage points each. The bulk of the projects fall within the range of 15 to 40 percent. Individual projects fall in a wider range of 0 to more than 55 percent for the year. The median CF value for 2016 was 25 percent, and the Robertsons Ready-Mix in Riverside County plant achieved the highest factor at 56 percent. From 2014 to 2016, the maximum annual project CF increased as more small commercial projects were brought on-line, and these projects typically had high factors.

Figure 11: Distribution of Project Capacity Factors



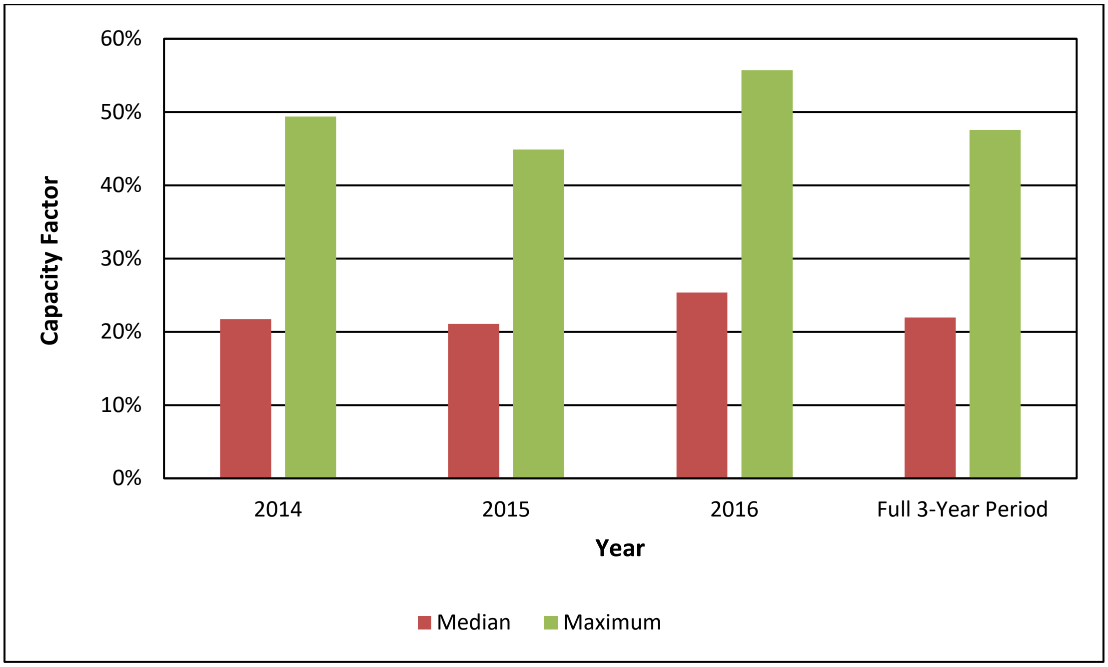
Source: WPRS data set of the California Energy Commission

Compared to the annual CFs for the whole fleet by year (**Table 1**), maximum individual project CFs can be higher. Zero values are from projects that are available to generate but produce little or nothing during the period. A turbine or group that was available to generate in the reporting period includes those that were operable and able to generate electricity. It includes turbines that may not have been generating due to temporary outages, contractual issues, or short-term equipment repair. The maximum and median CFs by year are graphed in **Figure 12.** The three-year period maximum was lower than the 2016 maximum, as is expected with a maximum value over a longer period.

Turbine Capacities

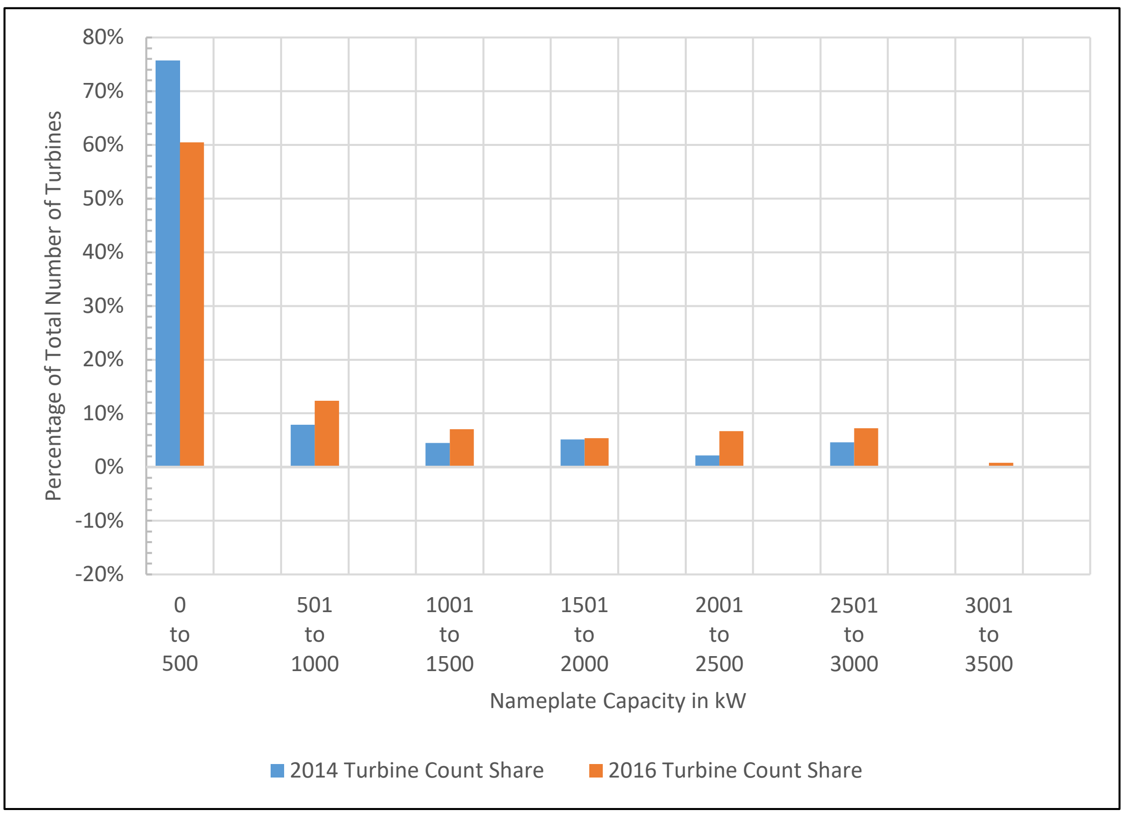
Over the three-year period, the in-state turbine fleet showed a shift toward larger-capacity turbines as smaller turbines were taken out of service. **Figure 13** depicts the composition of the fleet by turbine count shares broken into turbine capacity ranges. Bars depict the shares for the first quarter of 2014, the last quarter of 2016, and the change in percentage points between the quarters. These are broken into 500 kilowatt (kW) size increments. The percentage of the number of turbines in the zero kW to 500 kW range decreased, and those in the 1,501 kW through 2,000 kW range remained essentially the same. Other capacity ranges increased the percentage of the total number of turbines. Small turbines made up most of the fleet by turbine numbers at the beginning and end of the three-year period.

Figure 12: Maximum and Median Capacity Factors



Source: WPRS data set of the California Energy Commission

Figure 13: Percentage of Total Turbines by Turbine Size

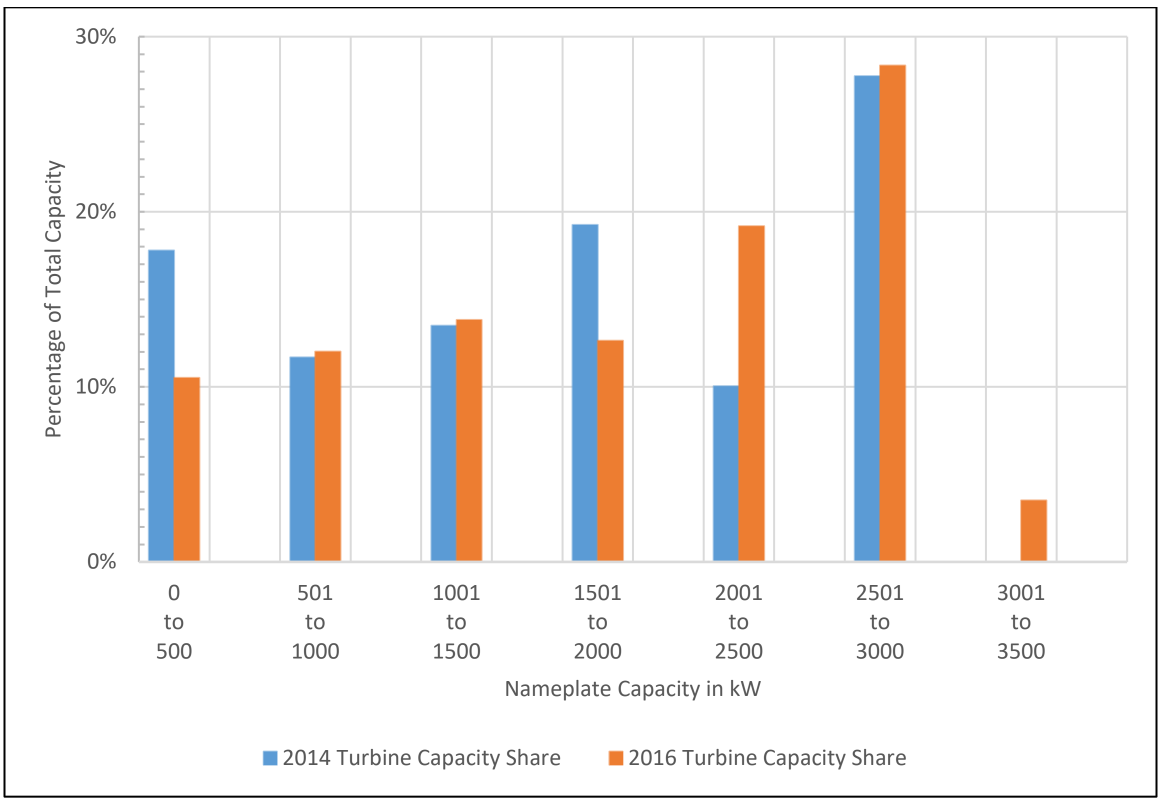


Source: WPRS data set of the California Energy Commission

When analyzed by the capacity composition of the fleet, data show that the larger shares of capacity are in the higher size ranges, as shown in **Figure 14**. Here the importance of the range above 2,500 kW up to 3,000 kW is visible. The shares composed of the up-to-500-kW and the 1,501-kW-through-2,000-kW sizes decreased. The other sizes increased or remained stable. Notably, the 3,001 kW through 3,500 kW sizes entered the fleet during this period.

Although the number of turbines in the fleet is lower in 2014, total fleet capacity is decreasing only slightly due to substitution with higher-capacity models. The largest turbine installed in the state is now 3.3 MW. Many of the smaller turbines use primitive technology by current standards and are not equipped with modern electronics. Technology in new projects allows for condition monitoring, fault diagnosis, and operational control from remote operation centers. Turbine sizes offered for sale are increasing around the world. Manufacturers bring larger turbines to market and can offer a lower cost of energy (COE) due to economies of scale. Much of the technology development today is focused on reducing the COE. Changes in turbine sizes by wind resource area (WRA) are detailed in the following chapter on regional generation.

Figure 14: Percentage of Total Capacity by Turbine Size



Source: WPRS data set of the California Energy Commission

Further Turbine Fleet Changes

In comments filed with the California Public Utilities Commission (CPUC), the California Wind Energy Association (CWEA) identified a number of existing projects likely to be in need of repowering (CWEA, 2017). These are broken down as shown in **Table 3**. This estimate is based on expiring contracts in 2014 compliance filings of the investor-owned utilities (IOUs) with the CPUC.

Table 3: Wind Repowering Candidates

Area	Nameplate Capacity (MW)
Altamont	98
San Gorgonio Pass	324
Tehachapi	709
Total	**1,130**

Source: California Public Utilities Commission

As of October 2017, CWEA estimates that 627 MW are already recontracted, repowered, or new. The status of the older projects and the financial pressures they face is clarified by a statement of CWEA:

> While some of these projects have already been repowered with modern technologies and are under new, long-term contracts, as much as 1,130 MW are still comprised of 1980s-vintage technologies that would be over 40 years old by 2030. Most of these projects are either in the last few years of their 1980s-era "QF" [qualifying facility] contracts, are operating under short-term contracts, or are selling directly into the California-ISO market.[3]

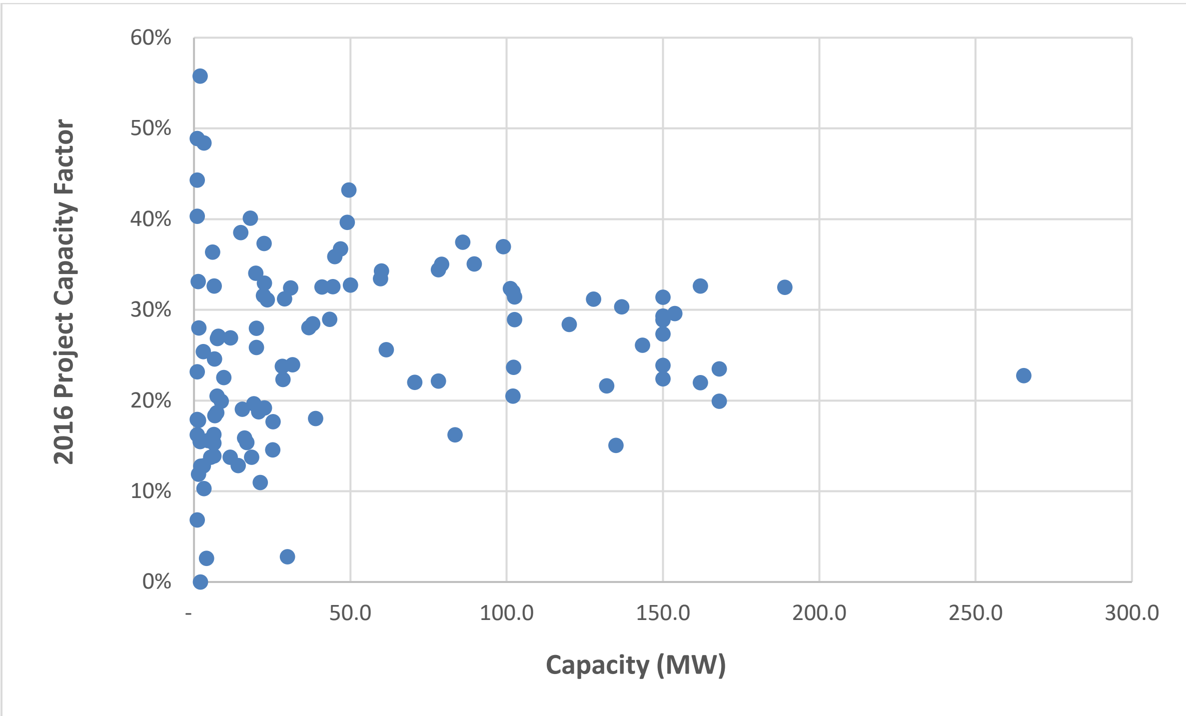
Capacity Factor Compared to Capacity

The CF of each project in 2016 is compared to nameplate capacity in **Figure 15**. At the small project sizes, there is a wide range of CFs, from zero to 56 percent. Factors converge to a narrower range at the large sizes, and among the 10 largest projects, they range from 20 to 33 percent. Examples of different sizes and capacity factors include Mogul Energy (4 MW and 3 percent CF), Wagner Wind (6 MW and 36 percent), and Alta II Wind Energy Center (150 MW and 27 percent). The high CFs of many small projects demonstrate that it is possible to attain high factors at smaller project sizes through a combination of project technology and operation. Current turbine technology and project engineering practices allow turbines and towers to be selected for particular site conditions, taking into account the particular wind regime at each site. Many of the small projects could show increased CFs through modernizing equipment, repowering,

3 California Wind Energy Association (CWEA). 2017. "Comments of the California Wind Energy Association on Proposed Reference System Plan and Related Commission Policy Actions." California Public Utilities Commission, Rulemaking 16-02-007, October 26, 2017.

or making other improvements to boost productivity. Such improvements would need to be economical for project owners, and many owners of older projects are currently not finding it beneficial to upgrade project equipment. However, tax credits and financial incentives can improve the economics of projects.

Figure 15: Capacity Factors vs. Capacities of All Projects in 2016

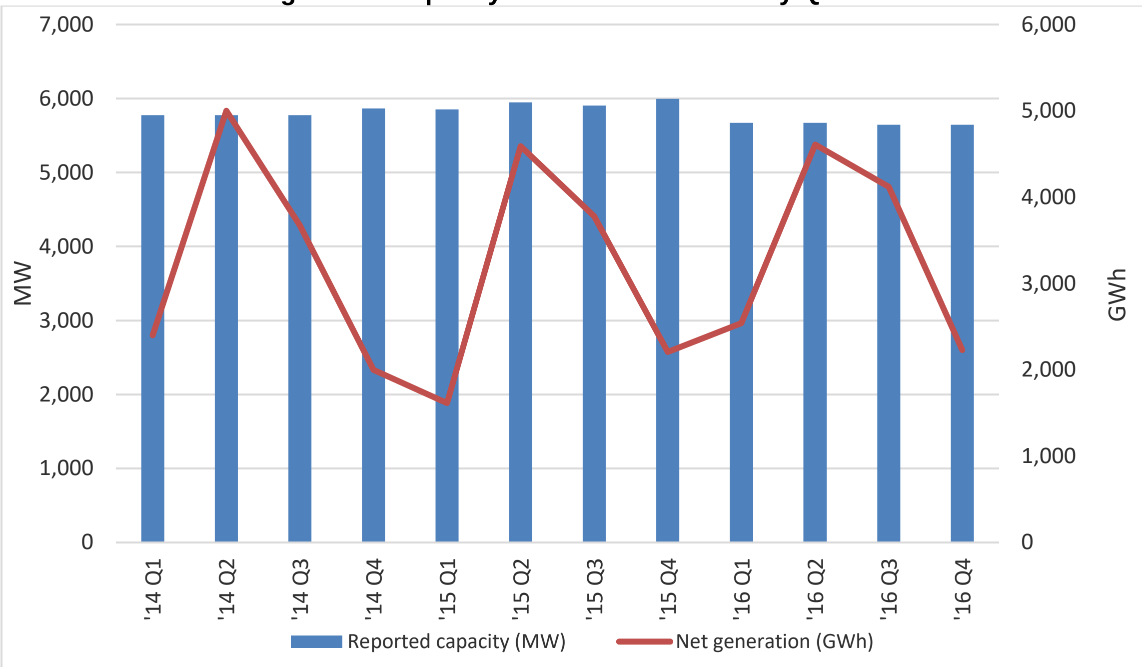


Source: WPRS data set of the California Energy Commission

Energy Generation

Over the three-year period, net reported generation was 38.8 terawatt-hours (TWh), with an average of 12.9 TWh per year. This amount represents 24 percent of the in-state renewable energy generation and 7 percent of all in-state generation. The pattern of wind energy generation over the three years was similar to the pattern of CFs, with the difference being that generation is the result of several factors, including changing capacities over the period. **Figure 16** displays capacity and net generation. Capacity increased modestly through 2015 and then decreased. Net energy traced a cyclical pattern, similar to the CF cycles. Breakdowns of the energy generation by part of the state are presented in the discussion on “Wind Resource Areas” in the chapter on “Regional Generation."

Figure 16: Capacity and Net Generation by Quarter



Source: WPRS data set of the California Energy Commission

Station Use Energy

Energy to operate the plant is referred to as the *station use*. Net generation is the difference between gross energy produced by a generator and energy used to operate the plant, including plant lighting, power, and auxiliary equipment. Wind generation operators report the gross energy and station use, and the WPRS software calculates net energy. Although many operators know the station use of the plant, some do not have these data because of the metering installed. However, station use is a small percentage of gross energy, and median values at the plants in 2016 ranged from 1 to 2 percent of energy, varying by month. During most months of the three-year period, median station use was 1 to 2 percent. The first quarter of 2015 had low wind speeds, and station use reached an unusually high value of 4 percent that January. All other months during the period were under 3 percent. The highest percentages generally occur in winter months, when production is lower. The lowest percentages generally occur in the summer months, when production is higher. Station use energy is essentially a fixed cost to the generation operator, whether production is high or low.

CHAPTER 3:
Other Parameters of Generation Projects

In addition to capacity, energy, and capacity factor, wind generation projects can be characterized by other parameters. These include rotor swept area, specific power, and specific energy. Along with reported values of swept area, quantities reported by operators can be used to calculate additional measures of power and performance. These include specific power and specific energy, both of which are widely used in the industry and in research and development. Examining the projects in these ways advances understanding of the productivity of wind plants within the state.

Rotor Swept Area

The swept area of a turbine rotor is the circular area defined by the rotation of the blades. Modern turbines have a nearly horizontal axis, so the swept area is an area within a nearly vertical plane. The offset from vertical is designed so that the flexible blades will not hit the tower. Although energy production often increases as swept area does, several factors affect this relationship, as discussed under the section "Specific Power" below.

Between 2014 and 2016, the most common rotor areas in service changed with the composition of the fleet. **Table 4** lists the ranges and the most common sizes in the fleet. To get a sense of these areas, a basketball court is 436 square meters (sq. m); an American football field with both end zones is 5,354 sq. m; and a standard soccer field is 7,140 sq. m. The largest rotors in service in California are nearly 10,000 sq. m, making them larger in area than a soccer field.

Table 4: Composition of the Turbine Fleet by Rotor Area

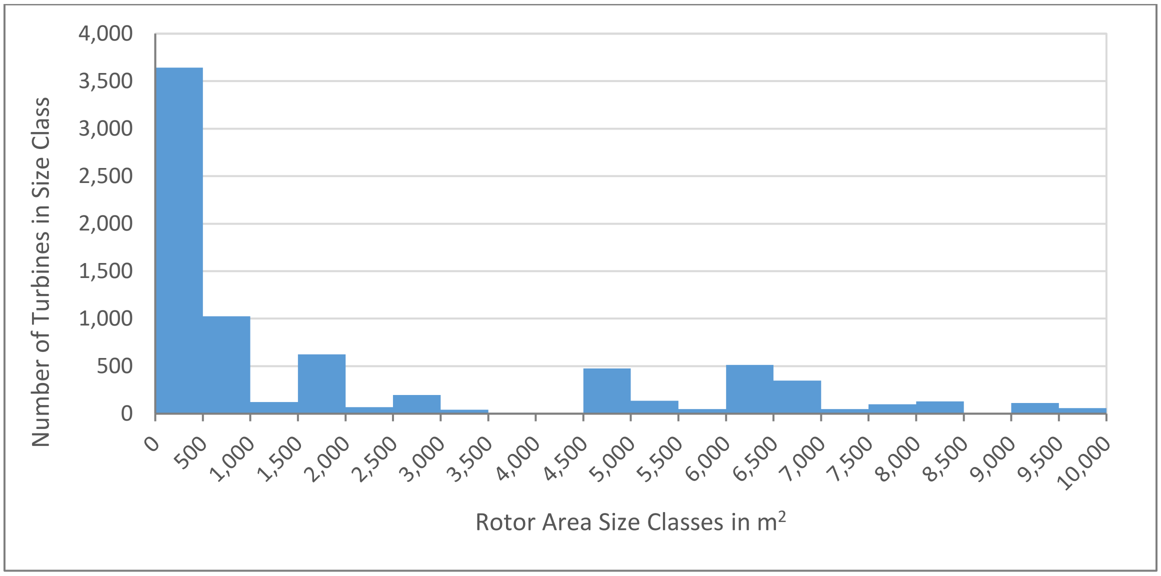
Close of 4th Qtr.	Smallest Area (sq. m)	Radius of Smallest (m)	Most Common Area (sq. m)	Radius of Most Common (m)	Largest Area (sq. m)	Radius of Largest (m)
2014	141	6.7	254	9.0	9,852	56
2015	141	6.7	254	9.0	9,852	56
2016	154	7.0	177	7.5	9,852	56

Source: WPRS data set of the California Energy Commission

From one-year end to the next, the largest rotor area remained the same. The smallest area increased slightly, while the most common size decreased. Many smaller turbines were removed from service at the end of 2015. Turbine rotor areas made and offered for sale have been increasing nationally and worldwide. The largest turbines for sale are larger than the largest ones currently installed in the state. Worldwide, turbines up to 90 m radius are in or nearing production.

Figure 17 depicts the distribution of the fleet by rotor area classes. The chart illustrates that the fleet is heavy in the smaller rotor sizes (such as 0 to 500 sq. m). More than half of those available to generate have rotor areas under 600 sq. m. Much of the in-service fleet comprises older models, smaller than those installed in new projects.

Figure 17: 2016 Distribution of Turbines by Rotor Area



Source: WPRS data set of the California Energy Commission

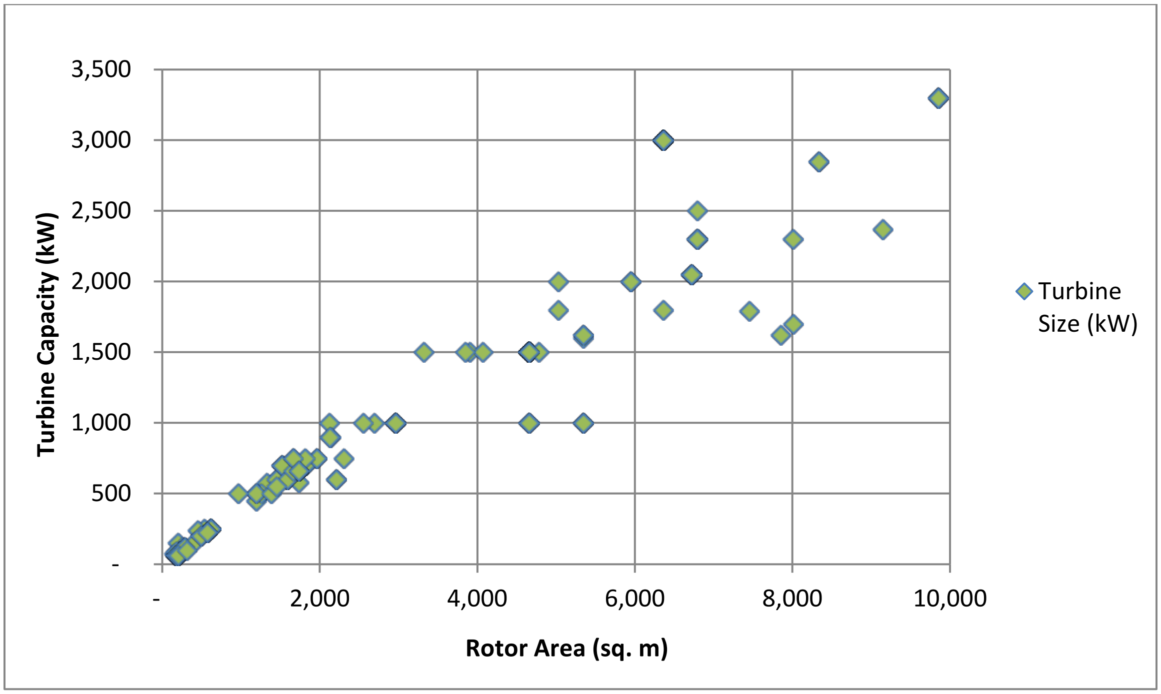
Specific Power

Specific power measures the amount of generator power per unit of rotor area, measured in watts per square meter (W/sq. m). It depends on the capacity of the electrical generator and the size of the turbine rotor. It is a parameter of the turbine model and can be changed by modifications of the turbine blades or rerating the generator. Specific power for a subset of the smallest reporting projects in the state is also affected by the derated capacities mentioned above. With the capacity derated, the rotor area is unchanged, and the specific power value decreases. This affects only a small fraction of all projects. The median specific power of turbine groups ranged from 187 to 750 W/sq. m, with the median at about 380 W/sq. m.

Manufacturers have offered designs of lower specific power to the market in recent years for use at lower wind-speed sites. This trend was not visible in the California data, which may reflect the lack of a significant movement so far toward lower-speed sites. Future growth may see expansion into new parts of the state with lower average wind speeds.

At the end of 2016, there was a close relationship between turbine capacity and rotor area. **Figure 18** depicts the capacity versus area for each turbine group. The number of turbines in each group varies, as listed in Appendix A. The larger-rotor turbines were present in a range of capacities.

Figure 18: Distribution of 2016 Specific Power by Turbine Group



Source: WPRS data set of the California Energy Commission

Specific Energy

Specific energy is a measure of the energy produced per unit of rotor area, measured in kWh per sq. m, and it can change with rotor modifications. It is calculated using turbine group gross energy generation and rotor area. Operators report gross energy production of turbine groups; that is before station use energy. Gross specific energy values are indicated in **Table 5.** The values include all turbine groups that operated during the year, including part of the year. The median shifted from year to year as operators changed the turbines in service. A turbine group reporting low energy production results in a low specific energy. This low production can occur if a group is undergoing short-term maintenance but is not retired. The effect of the low wind speeds in 2015 is visible in the lower median and maximum specific energies that year.

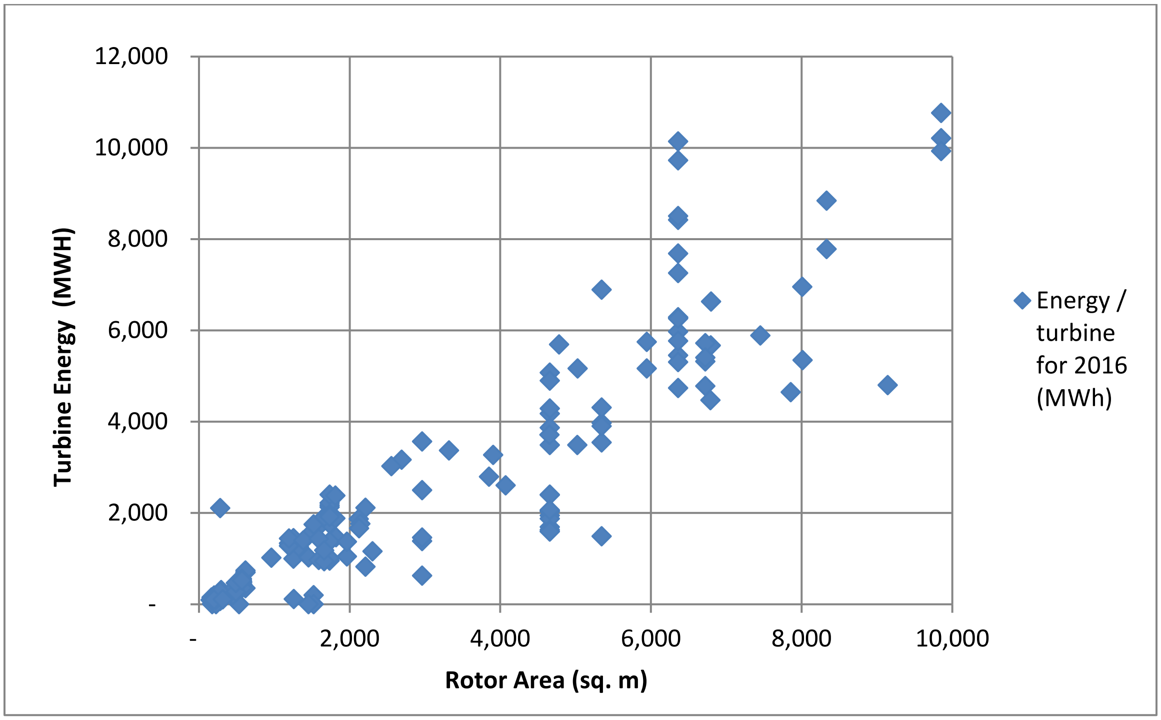
Table 5: Specific Energy Ranges (kWh/sq. m)

Year	Minimum	Median	Maximum
2014	1	712	2,155
2015	12	671	1,366
2016	90	787	1,594

Source: WPRS data set of the California Energy Commission

The relationship between gross energy produced and rotor area is noticeable, as shown in **Figure 19**. The graph shows the energy per turbine versus the turbine area. There is an increasing spread in energy at larger rotor sizes. Larger turbines are typically newer and have more effective control systems that can optimize energy production.

Figure 19: Distribution of 2016 Gross Specific Energies by Turbine Group



Source: WPRS data set of the California Energy Commission

To illustrate the relationships between these parameters, two examples of particular turbine groups are detailed in **Table 6**. The first is a turbine group in the older Wind Resource II project, and the second is a group in the newer Rising Tree III project. The table shows the reported values of rotor area, capacity, and energy, and the related effects on the derived values of capacity factor, specific power, and specific energy.

Table 6: Comparison of Turbine Groups

Project, Group, & Start Yr.	Turbine Rotor Area (sq. m)	Turbine Capacity (kW)	Capacity Factor	Specific Power (W/sq. m)	Annual Energy /Turbine (MWh)	Specific Energy (kWh/sq. m)
Wind Resource II, Bonus, 1984	201	65	19	323	107	533
Rising Tree III, RT III, 2015	9,852	3,300	37	335	10,767	1,093
Ratios	49	51	2	1	100	2

Source: WPRS data set of the California Energy Commission

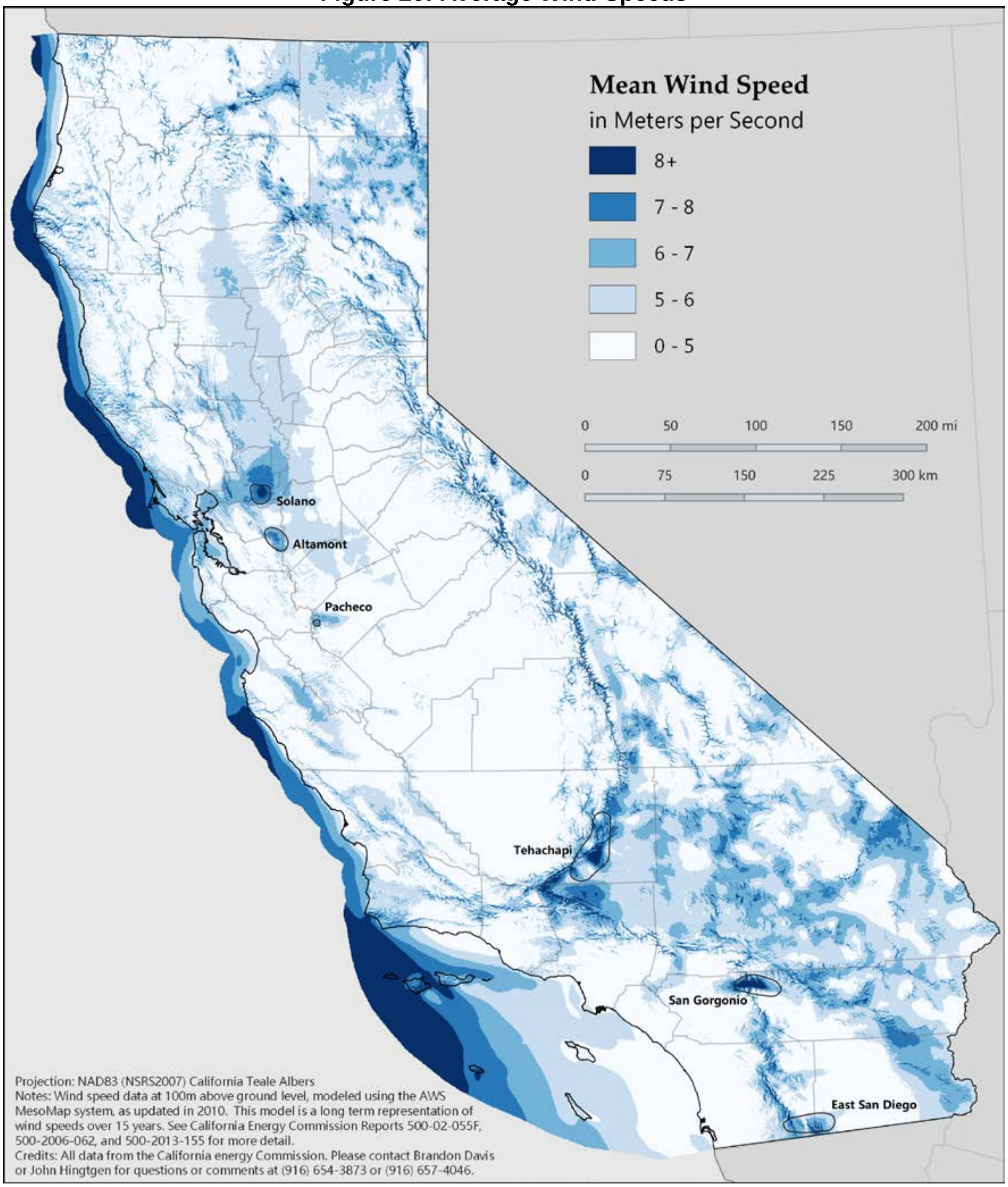
In comparing the newer Rising Tree III project to the older Wind Resource II project, the newer project turbines are 49 times larger in area, are 51 times larger in capacity, and produced 100 times as much energy per turbine as the older project. The newer turbines had about the same power per unit of rotor area. The newer project achieved a capacity factor twice as high and produced two times as much energy per unit of area. The higher productivity of the newer project benefits from more advanced technology and more sophisticated project engineering and design.

California's wind projects exhibit a wind range of capacity factors. In addition to characteristics of the turbine, natural factors also affect the CF. Projects in the state are installed in a range of climates. Each climate has many wind speed distributions within it. These wind speed distributions vary across topography, elevation, and slope aspect, as well as more indirect factors such as distance from the coast. The climate affects the distribution of wind speeds at a site, which affects the ability of a turbine to produce electricity over time. These factors are in addition to parameters of the turbine itself. The resulting energy production affects the capacity factor the turbine attains.

Wind Speeds and Variations from 2014 Through 2016

The power available to wind generation projects is strongly affected by the set of wind speeds occurring at the turbines. Wind power is proportional to the cube of the wind speed. Variations in wind speeds (averages, maxima, and speed distributions over time) affect the energy of the wind that is available for conversion into electricity. Speed variations occur over different time scales and across geographic areas, and available power varies over time and space, both horizontally and vertically. In addition to varying by location and time, speeds and speed distributions vary by direction of the compass. These variations can be summarized by stating that wind speeds are both heterogeneous and anisotropic, in addition to varying over time.[4] Long-term average wind speeds across the state are shown in **Figure 20**

Figure 20: Average Wind Speeds



Source: California Energy Commission, Supply Analysis Office

4 Heterogeneous refers to a property that varies from point to point across space. An example is air temperature. Anisotropic refers to a property that varies according to direction. An example is the strength of sunlight.

The distribution of speeds over a period at a point in space is also probabilistic (stochastic). This means that although one can estimate the speed and direction (and the power and output) at a point, the natural and artificial variables affecting a turbine combine to produce an output that cannot be known precisely in advance using current science. Better methods to estimate expected speeds are an area of active research.

WRAs are in some of the better onshore wind resource areas, although other areas of high winds are undeveloped. The established WRAs are fairly close to electric load centers or to transmission lines that enable energy to be delivered to markets, generally toward the coastal side of the state.

In addition to the onshore areas, offshore wind resources exist off the coast of California. Some California companies and universities are developing technology to capture the offshore wind power. High average wind speeds offshore of many parts of the coast are evident in **Figure 20**. These include areas from the Oregon border to seaward of the Channel Islands of Southern California. These parts of the state are potentially regions for future offshore wind development, subject to planning constraints, economic conditions, and public acceptance.

Variations in wind speed from the average have been determined and mapped (AWS Truepower, 2107), and the variations from the base 1988 to 2014 average are shown in Appendix B**.** These maps capture the variations by time and location but not those by direction. In practice, project designers now also make use of wind direction data to estimate power output. In 2014, wind speeds were below average for most of the state but above average for the middle of the Central Valley and the northern portion of the state. In 2015, speeds were below average for all but a few pockets of the state. In 2016, speeds were below average over about half the state and above average over the northeast and south central portions of the state. Speeds on these yearly maps and on the average speed map are depicted at 100 m high. This is in the range of likely future wind projects as technology improves and towers become taller.

Wind speeds across North America were below average in 2015, especially in the first half, as strong winds were diverted north of California. As explained by Brower (2015).[5]

> The most direct reason for the low winds across much of North America in early 2015 was a large high-pressure system, known as a ridge, that formed over the eastern North Pacific… this system caused winter and spring storms to take a big detour into Canada before dipping back into the United States.

Although wind speeds varied significantly from year to year, CFs varied only modestly, and this is an interesting finding. This finding testifies to the adaptability of generators. Newer turbines and projects are self-controlled by software at the turbine or control

[5] Brower, M. December 9, 2015. "The North American 'Wind Drought': Is It the New Normal?" Web page, https://www.awstruepower.com/the-north-american-wind-drought/

station, and the software adjusts to changing wind conditions. Some projects also have software to optimize production for the whole project, considering the effect of all the turbines within the project and the associated interactions, such as wake effects. Older turbines may be controlled by mechanical devices that adjust only to varying wind speeds.

CHAPTER 4:
Regional Generation

Wind Resource Areas

California wind generation occurs is established in six regions, known as WRAs: three in the north and three in the south. Tehachapi is the largest of these in area, and Pacheco is the smallest. **Table 7** lists the WRAs, the counties in which they occur, and the included areal extents (in square km).

Table 7: Wind Resource Areas, Counties, and Areas

Area (north to south)	Counties	Area (km^2)
Solano	Solano	285
Altamont	Alameda, Contra Costa, San Joaquin	345
Pacheco	Merced	30
Tehachapi	Kern	1,425
San Gorgonio	Riverside	645
East San Diego	Imperial, San Diego	705
Other Resource Area	Monterey, San Bernardino, Shasta, Tehama, Yolo	N/A
Outside Existing	San Joaquin, Solano	N/A

Source: Supply Analysis Office, California Energy Commission

In addition to the named WRAs, two more areas are used to localize projects. The category of “Other Resource Area” denotes projects in other parts of the state besides the traditional WRAs. The “Outside Existing” category indicates projects outside but near traditional WRAs. The WRAs are depicted in **Figure 21**. Only the portion of the state with WRAs and separated project locations is depicted, but projects extend from Northern California to near the southern border.

Figure 21: California Wind Resource Areas

Source: California Energy Commission, Supply Analysis Office and Cartography Unit

Projects Outside Wind Resource Areas

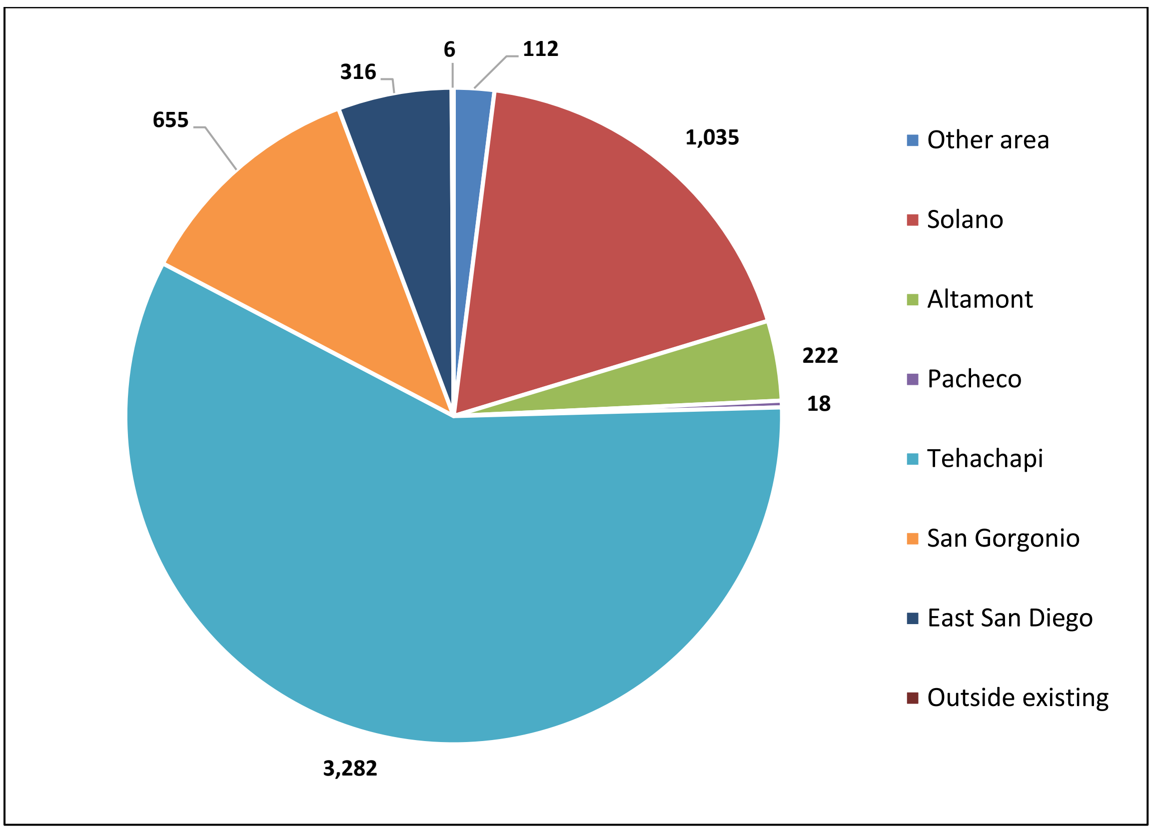
In addition to projects within WRAs, several projects are installed in other parts of the state. The smaller of these serve site users, which purchase their output for an adjacent user, typically a commercial facility. A few of those outside WRAs do not serve adjacent consumers, such as the Hatchet Ridge project. Projects outside WRAs are also depicted in the figure.

The lack of precisely defined WRA boundaries in the past led staff to define the boundaries in collaboration with the Energy Commission's Cartography Unit during analysis for this report. Using turbine and land-use parcel data to find the extent of existing wind infrastructure in each WRA, boundaries were drawn around these areas. Then, a smoothing algorithm was run to ensure each WRA was shaped simply and was suitable for application at the statewide scale. The boundaries are inclusive, with all turbines in each area included. There can be large distances from the boundary edge of a WRA to the nearest turbines; distances range from 1.3 km to 14 km, and the median distance is 6.3 km.

Capacity and Generation by Region

Of the total 5,644 MW of operational wind capacity in 2016, most of the capacity exists in the Tehachapi WRA with 3,282 MW. Smaller amounts exist in the Solano, San Gorgonio, and East San Diego WRAs, as depicted in **Figure 22**. The six established WRAs are listed from north (Solano) to south (East San Diego). Between the end of 2014 and the end of 2016, the Tehachapi and Solano WRAs saw an increase in capacity, while the Altamont and San Gorgonio WRAs saw a decrease.

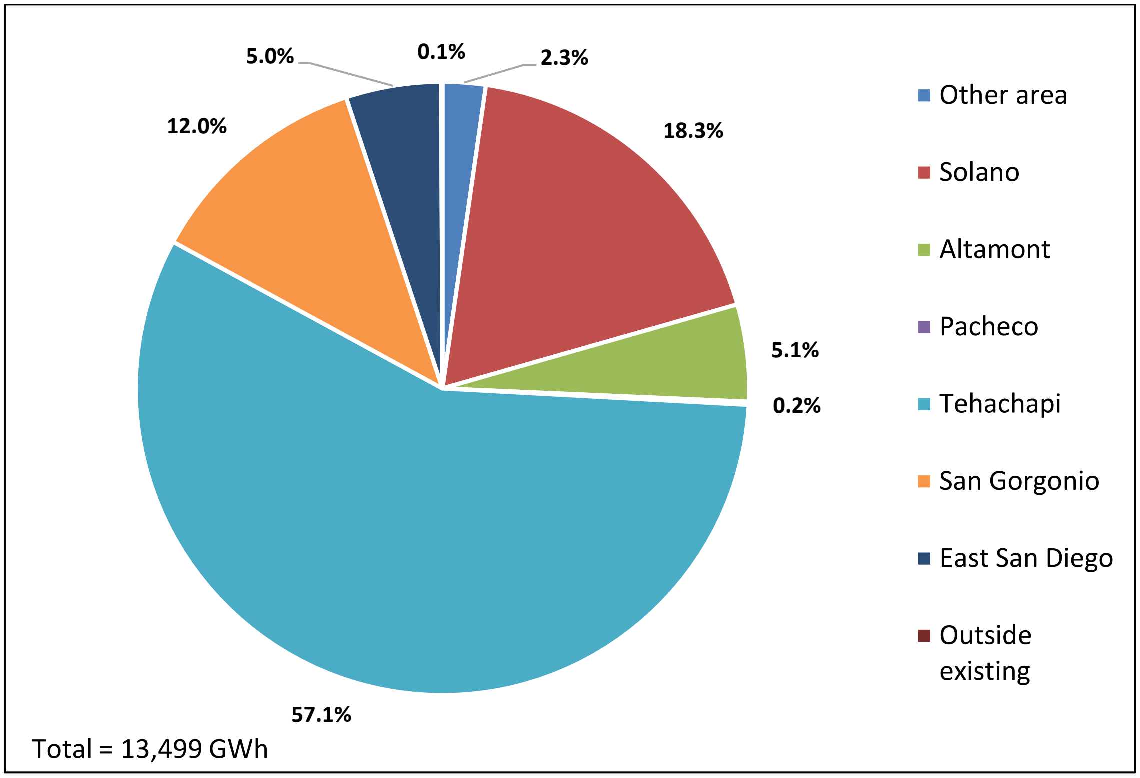
Figure 22: 2016 Capacity by Area (MW)



Source: WPRS data set of the California Energy Commission

Among the established WRAs, the Tehachapi area contributed by far the largest share of generation at 57 percent of the total, and Solano was second at 18 percent in 2016. Other WRAs had smaller shares of total generation. The category of Other Resource Area, with projects in nonestablished areas of the state, had 2 percent of generation, and this contributed to geographic diversification. **Figure 23** shows the breakdown in net energy by area for 2016.

Figure 23: 2016 Net Energy by Area

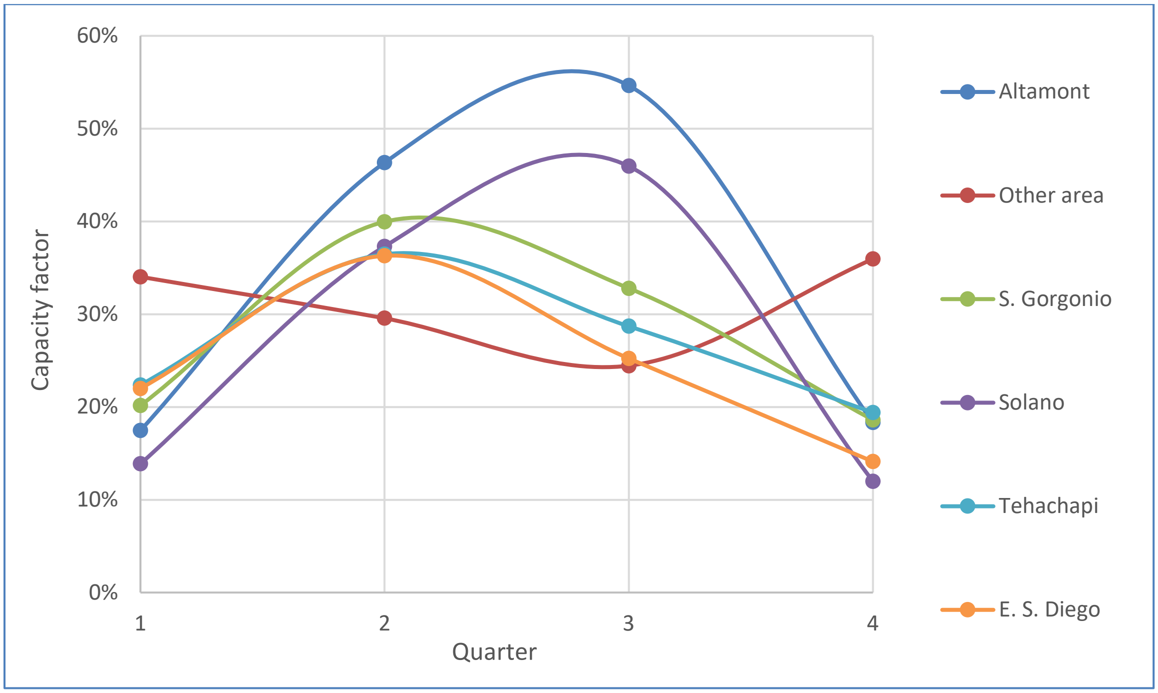


Source: WPRS data set of the California Energy Commission

Regional Capacity Factors

Each WRA in California exhibits a slightly different profile of generation over the year. The established WRAs show similarity in profile, peaking in the summer and being lower in the winter. Projects at the ends of the state show a complementary profile with a winter peak and minimum in the summer. **Figure 24** displays the CFs by quarter in 2016. Here, the summer peaking is apparent in five WRAs. Altamont and Solano peak in Quarter 3, while East San Diego County, San Gorgonio, and Tehachapi peak in Quarter 2. The Pacheco WRA is not included here, as it has much smaller capacity than the other five WRAs. The Other resource area comprises mostly the Hatchet Ridge project in Shasta County and peaks in the winter. This area has a roughly opposite profile than the other areas, and this is important to note. This complementary peaking increases generation diversity. Existing transmission constraints can limit the ability of system operators to make use of this diversity. However, transmission upgrades are a common type of electric system upgrade, used in California and around the world, to allow more renewable energy to be injected into the grid.

Figure 24: Capacity Factor Variation Among Wind Resource Areas in 2016



Source: WPRS data set of the California Energy Commission

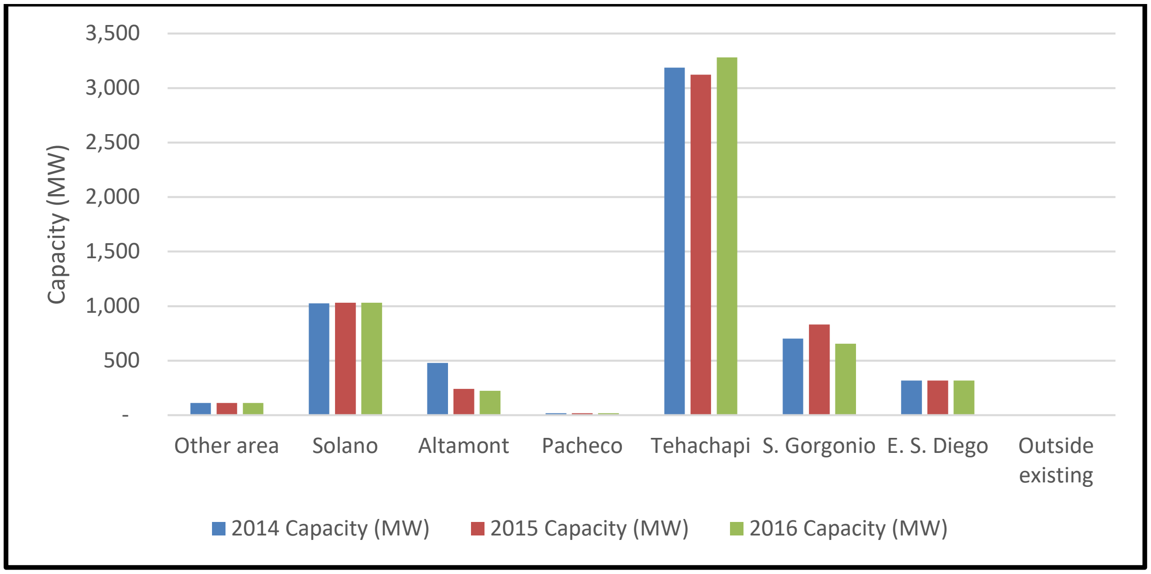
County Variations

Generation profiles by county also vary, and they exhibit differences in timing of the peaks. The top counties by CF in the state in 2016 are Monterey, Alameda, San Diego, Shasta, Contra Costa, and Riverside. These counties exhibit different peak times. There is early summer peaking in Riverside and Monterey Counties, late summer peaking in Alameda and Contra Costa Counties, and winter peaking in Shasta and San Diego Counties.

Changes in Wind Resource Areas Over the Period

When the WRAs are examined for changes over the period, interesting patterns emerge from the data. WRA capacity changes are shown in **Figure 25**, with the WRAs arranged generally from north (left) to south (right). The Tehachapi WRA, with more than 3,000 MW throughout the period, increased in capacity, in contrast to Altamont and San Gorgonio, which decreased. Solano, Pacheco, and East San Diego were stable.

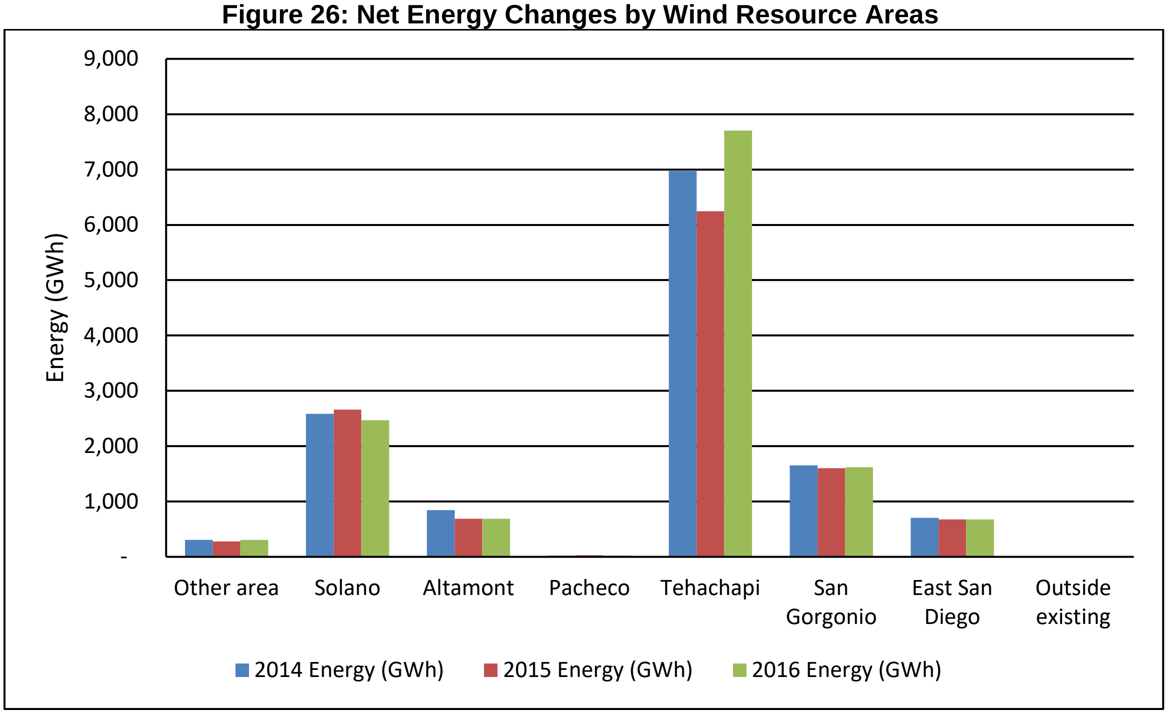
Figure 25: Capacity Changes by Wind Resource Areas



Source: WPRS data set of the California Energy Commission

Changes in the net energy produced by WRA show similar patterns in the relative magnitudes of the WRAs, as **Figure** 26 depicts, but the trends are different. Tehachapi showed the effects of lower wind speeds in 2015. Solano, however, had higher production in 2015 and lower in 2016.

Figure 26: Net Energy Changes by Wind Resource Areas

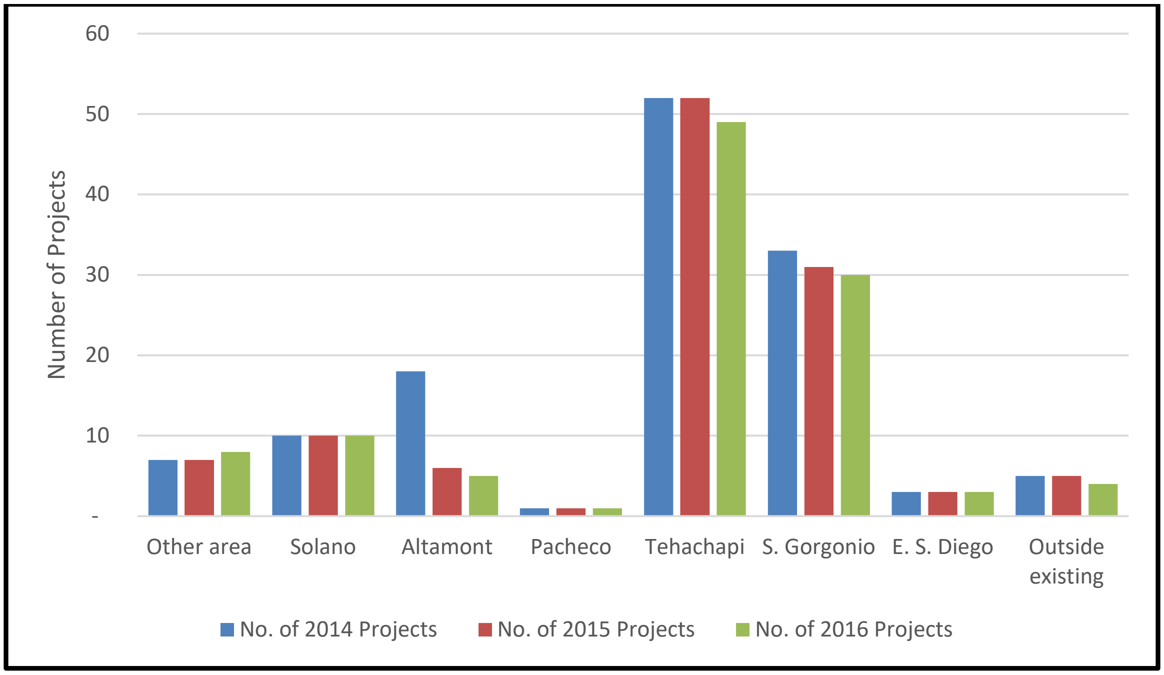


Source: WPRS data set of the California Energy Commission

Trends in the number of projects are shown in **Figure 27**. Altamont, Tehachapi, and San Gorgonio had decreasing numbers of projects, while the other areas group had an increase. The numbers include total projects by area. The change in number was especially pronounced at Altamont.

There is ongoing discussion in the wind energy industry and academia about the opportunities for replacing outdated equipment with modern equipment at existing project sites. Data specifically about repowering are not collected in the WPRS. However, supplemental information from operators indicates that California wind generation projects are in transition, as retirement of older turbines eases installation of newer technology.

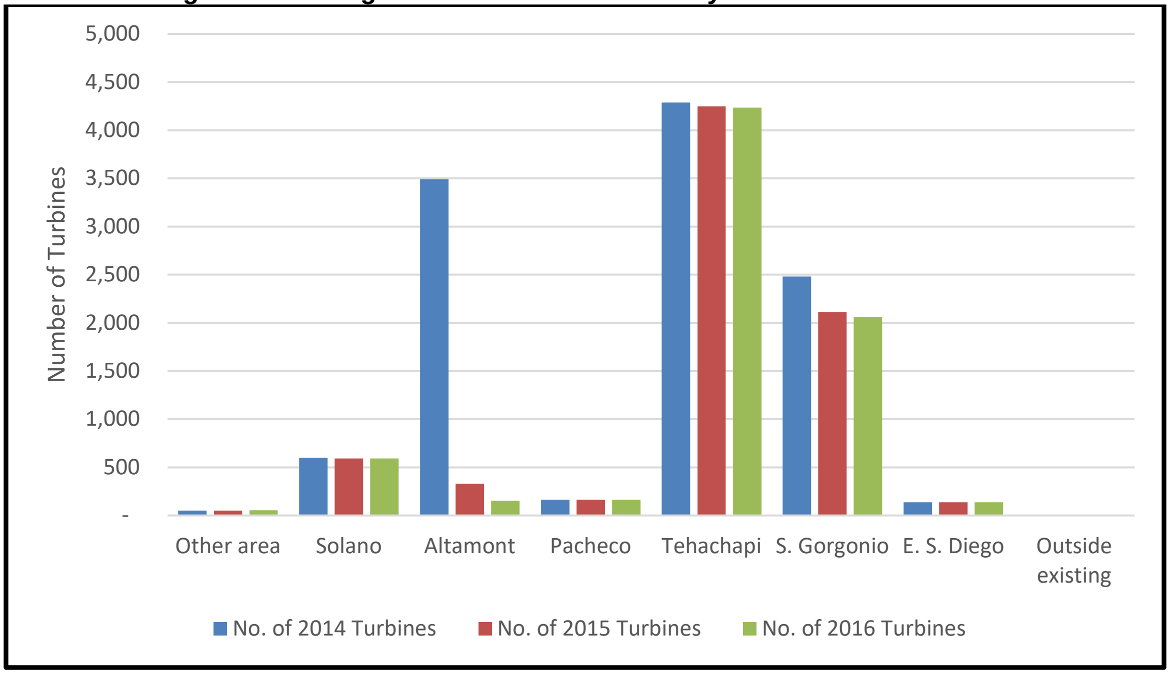
Figure 27: Number of Project Changes by Wind Resource Areas



Source: WPRS data set of the California Energy Commission

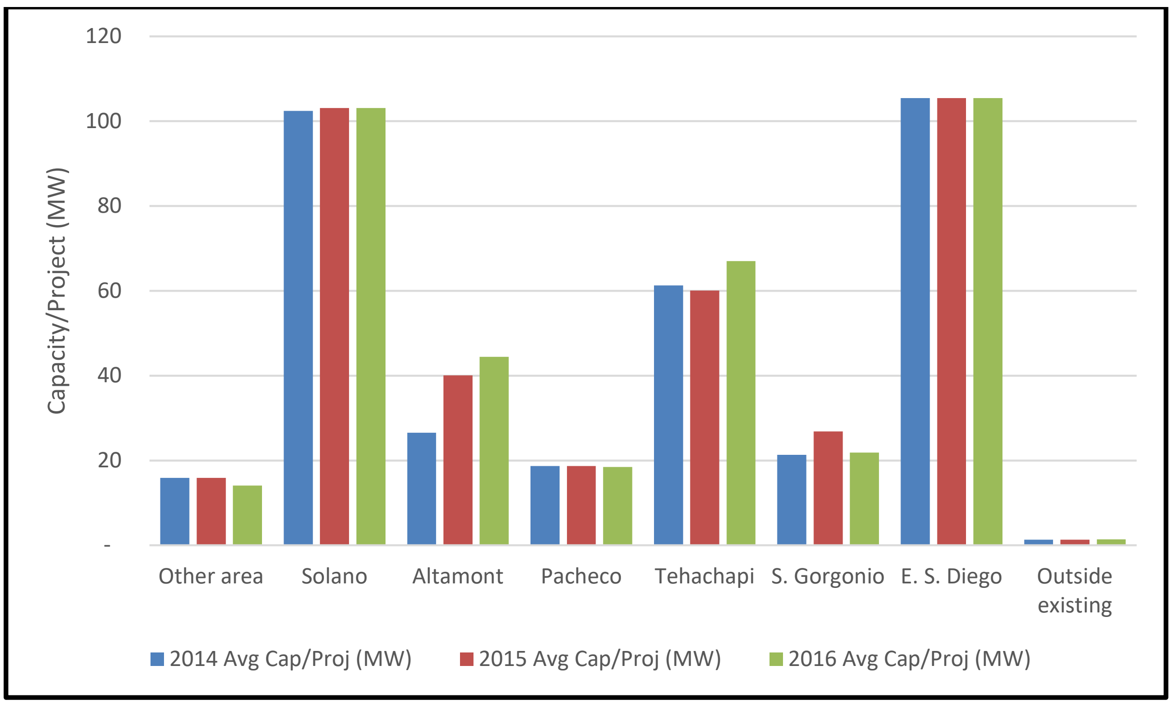
The numbers of turbines by WRA changed from 2014 through 2016, as in **Figure 28**. Altamont had the largest decrease. San Gorgonio also saw a modest decrease and Tehachapi a minor decrease. Other WRAs remained stable. The mean capacity per project increased at Altamont and Tehachapi, as **Figure 29** shows. Most other WRAs were stable in this measure.

Figure 28: Change in Number of Turbines by Wind Resource Areas



Source: WPRS data set of the California Energy Commission

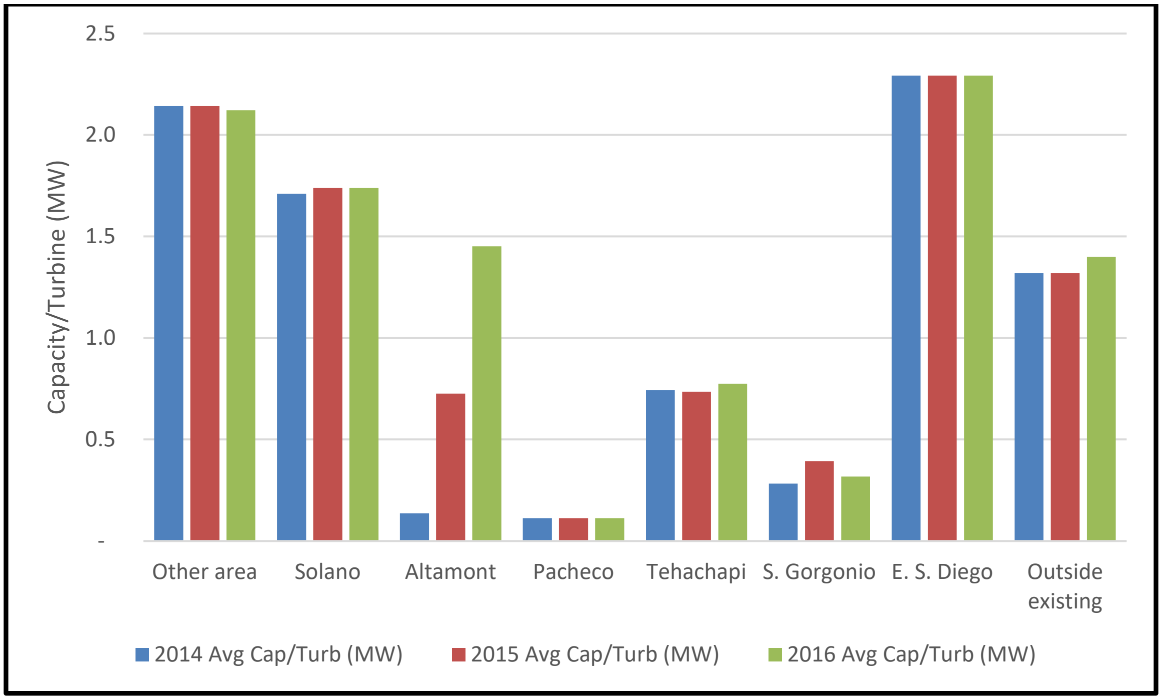
Figure 29: Change in Capacity per Project by Wind Resource Areas



Source: WPRS data set of the California Energy Commission

The average turbine size continued to evolve in most areas, as illustrated **Figure 30** showing the mean capacity per turbine. Altamont showed a marked increase, and there was a minor increase at Tehachapi. At Altamont, while the capacity of the WRA decreased significantly, the number of turbines fell several times over, leading to a much-increased capacity per turbine.

Figure 30: Change in Capacity per Turbine by Wind Resource Area

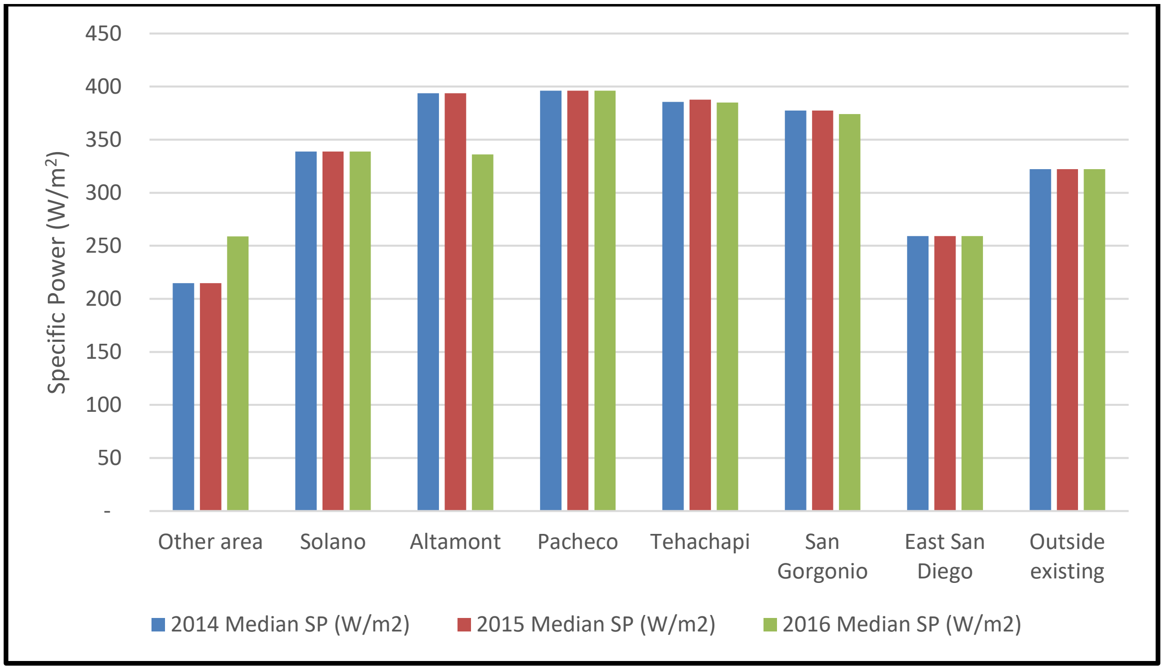


Source: WPRS data set of the California Energy Commission

Specific power (power per unit of area) changes over time by WRA, as shown in **Figure 31**. Values are the median of the turbine groups in each WRA. Most WRAs were stable. Altamont had a decrease in specific power, showing a shift toward a fleet composition of lower capacities with respect to rotor areas.

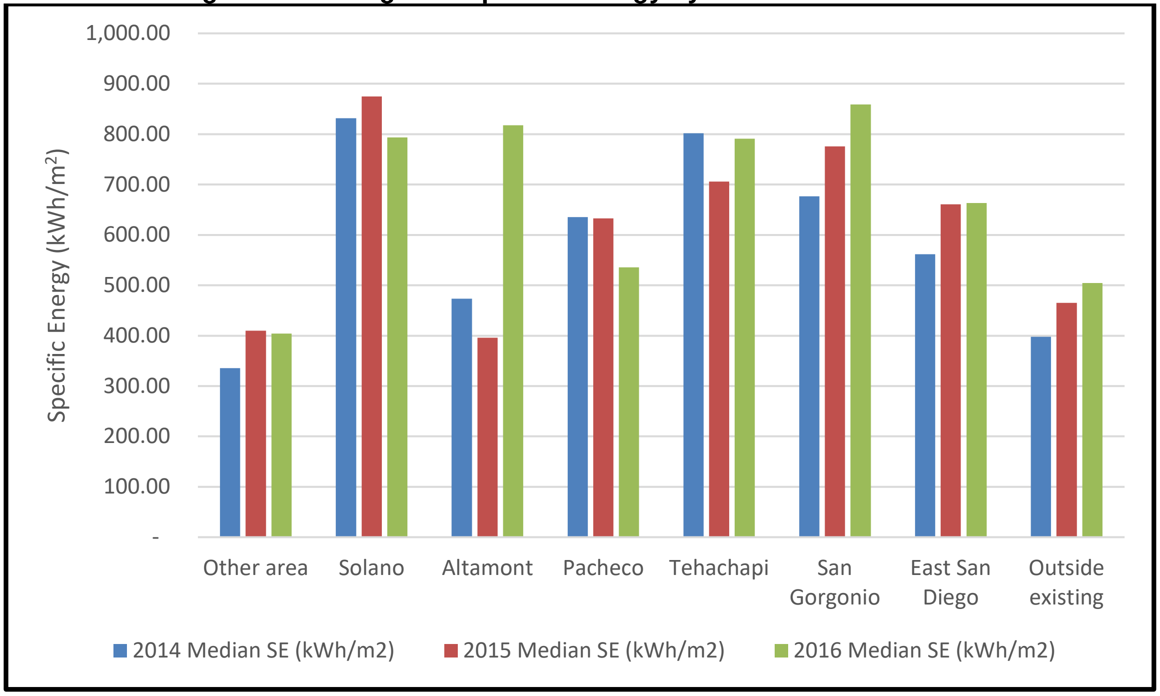
Specific energy (energy per unit of area) changed over time and by WRA, as depicted in **Figure 32**. San Gorgonio and the Outside existing category showed an increase over the three years. Altamont and Tehachapi values paralleled the lower wind speeds in 2015. Solano and the other area group were able to maintain good production in 2015, in spite of the lower speeds that year, possibly reflecting more adaptive control systems of turbines in those areas.

Figure 31: Changes in Specific Power by Wind Resource Areas



Source: WPRS data set of the California Energy Commission

Figure 32: Changes in Specific Energy by Wind Resource Areas



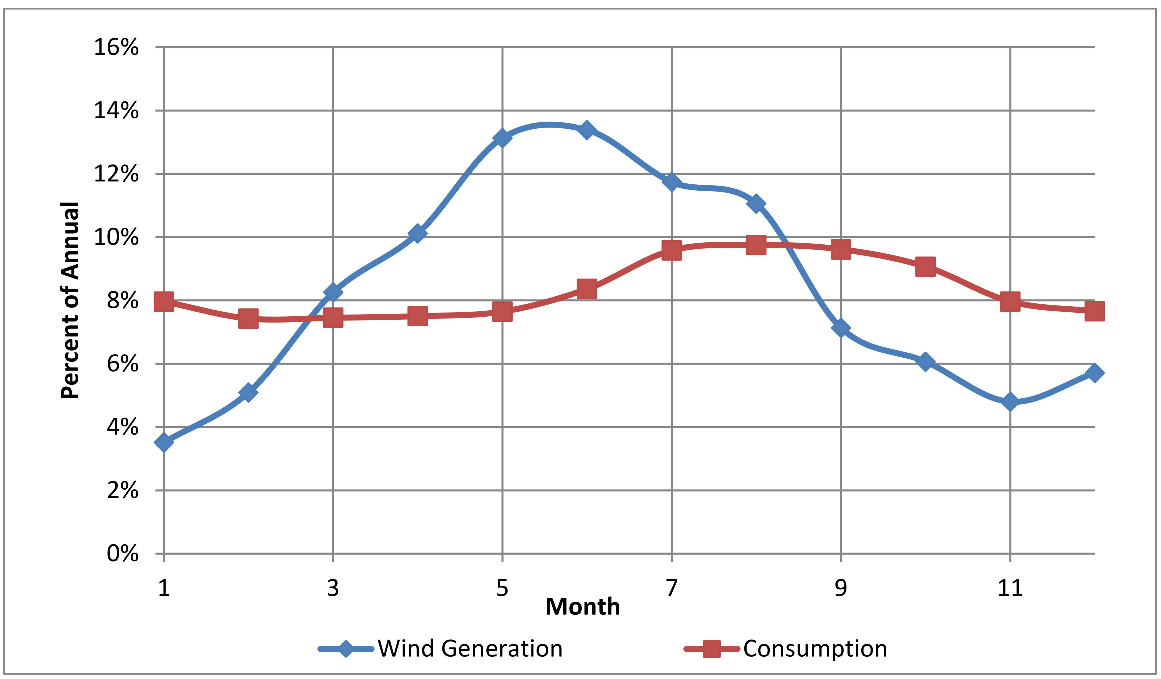
Source: WPRS data set of the California Energy Commission

CHAPTER 5: Comparison of Consumption to Generation

The season when generation occurs is important where consumption has a strong seasonal component. California consumption peaks in the summer when air-conditioning demand is highest. The profile of generation affects meeting this seasonal demand. Most renewable energy sources have seasonal variations, responding to cycles in the wind, sunlight, stream flow, and growth of biomass. Although energy management technologies can moderate these cycles, renewable resources vary over time.

Electricity consumption in California peaked in August of each year during 2014–2016 and reached the lowest points during February. This profile can be compared to the average generation for large wind plants as these plants represent the majority of statewide wind capacity and energy generation. Wind generation peaks in the midsummer, during June, with a minimum in January. **Figure 33** illustrates the average statewide profiles during this period. The vertical axis denotes percentage of the annual total consumption. Average peak generation occurred two months before the average consumption peak. The minimum wind generation occurred one month before the minimum consumption.

Figure 33: Statewide Profiles of Electricity Consumption and Wind Generation



Source: California Energy Commission, Supply Analysis and Demand Analysis Offices

The graphs compare the monthly differences in energy over a year between electricity consumption and wind generation. Other actions like increased efficiency, storage, and demand management can help bridge the differences between peaks of consumption and wind generation. Demand management and conservation price signals can motivate consumers to shift consumption to times of more abundant energy. As these technologies improve, bridging the differences becomes more feasible. Other renewable resources (solar, hydropower, geothermal, and bioenergy) each have distinct profiles. This is in contrast to conventional electric generation that can be dispatched independent of weather variations. Grid management considers all generation sources, renewable and conventional.

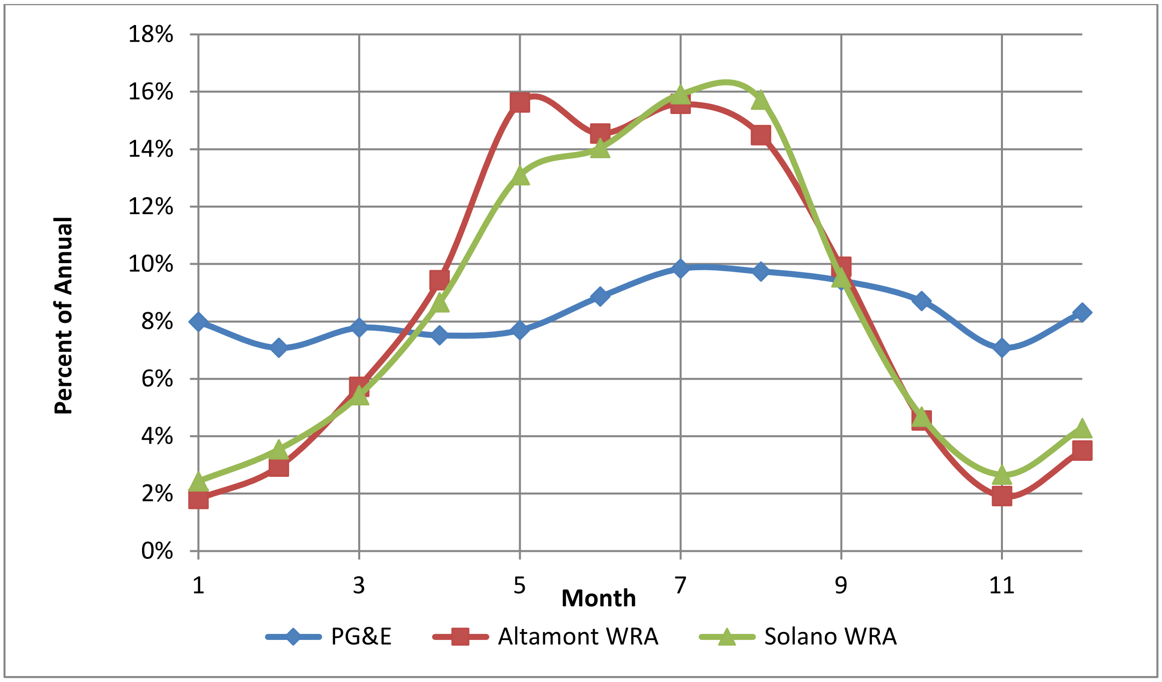
Generation and Consumption Profiles by Wind Resource Areas

The difference in peak timing is not uniform for all load-serving entities (LSE) or all WRAs. Each LSE has its own consumption profile, and the peaks of these occur earlier or later than the generation within WRAs. WRAs lie in the service territories of four LSEs: Pacific Gas and Electric (PG&E), Southern California Edison (SCE), San Diego Gas & Electric, (SDG&E), and Imperial Irrigation District (IID). The generation profiles of the five largest WRAs are compared here to the consumption profile of these LSEs. Comparison shows how closely each WRA profile and the corresponding LSE profile match. These are scaled to the same vertical scale, so the curves identify shape and timing differences, and the magnitudes of consumption and generation are normalized.

When the Altamont and Solano WRAs are compared to PG&E, generation and consumption profiles show the pattern as in **Figure 34**. PG&E consumption is somewhat steady over the year with a maximum in July. Generation at Altamont peaks in May and Solano peaks in July, so Solano more closely corresponds to the PG&E profile than Altamont does.

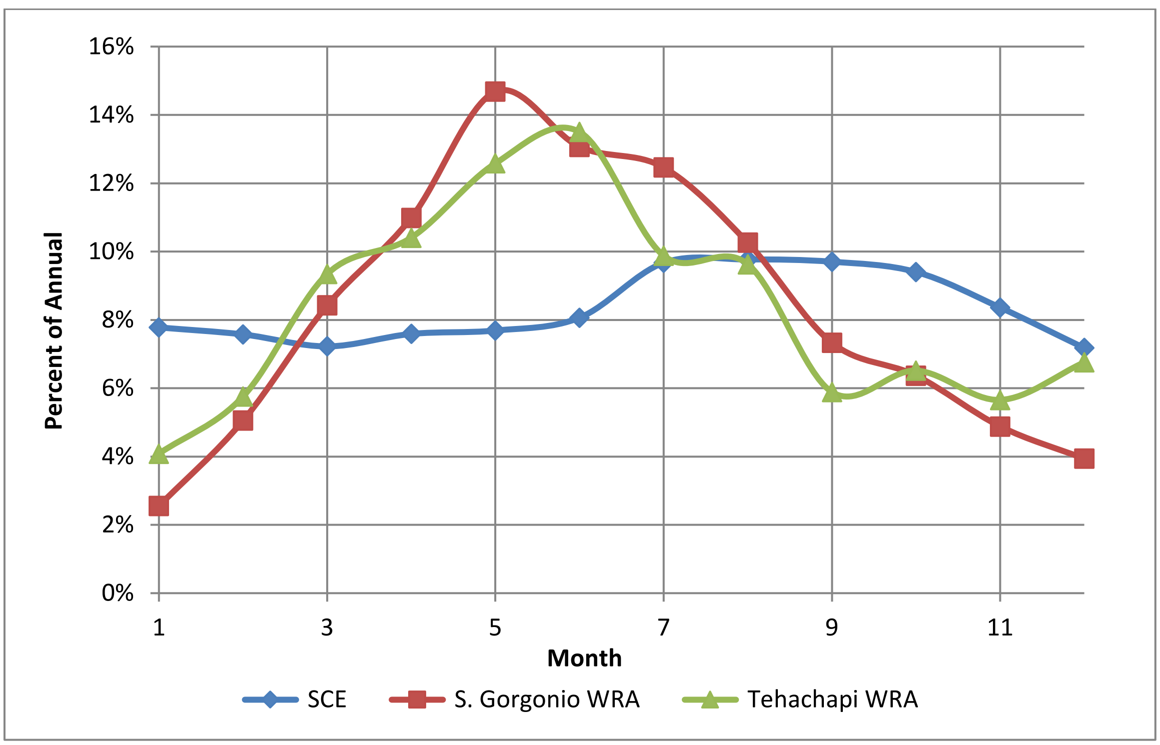
The SCE consumption profile can be compared to the two WRAs within its territory, San Gorgonio and Tehachapi, as in **Figure 35**. Generation at San Gorgonio peaks in May, while Tehachapi peaks in June, which are both earlier in the summer. Of the two WRAs, the Tehachapi peak corresponds more closely with SCE, which peaks in August.

Figure 34: Average Altamont and Solano Profiles with PG&E Consumption



Source: California Energy Commission, Supply Analysis and Demand Analysis Offices

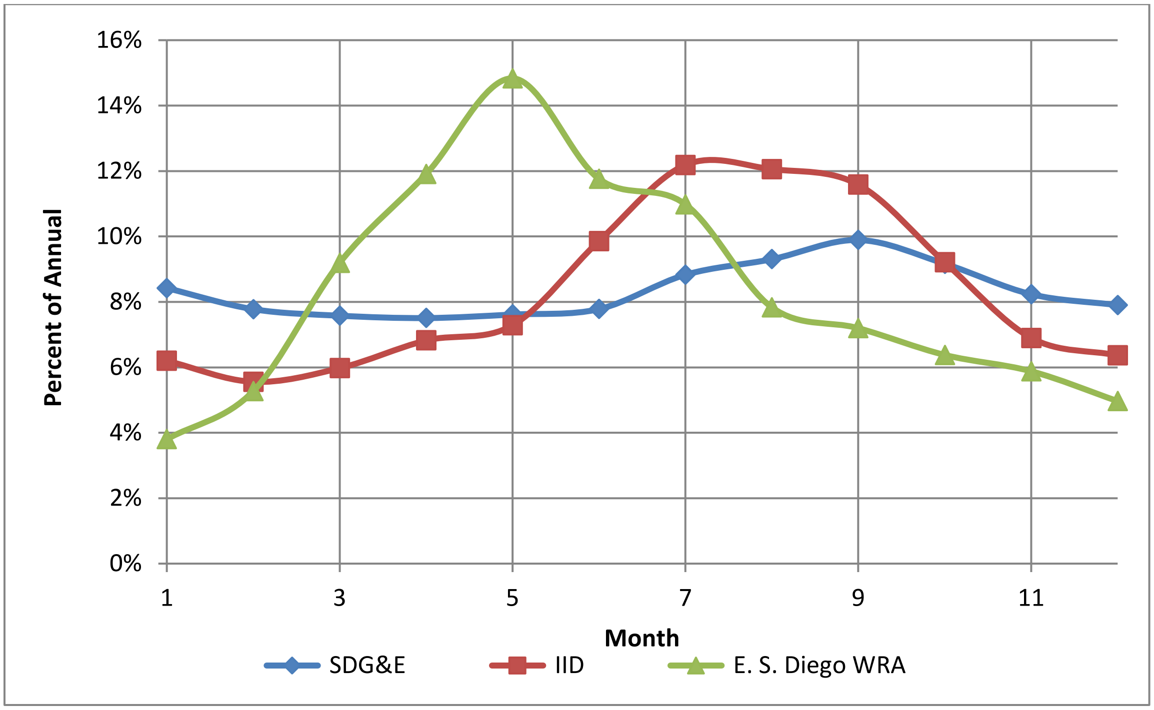
Figure 35: Average San Gorgonio and Tehachapi Profiles with SCE Consumption



Source: California Energy Commission, Supply Analysis and Demand Analysis Offices

The East San Diego County WRA lies in the IID and SDG&E territories. The consumption profiles of these territories are compared to this WRA in **Figure 36.** Generation in the East San Diego County WRA peaks in May. SDG&E consumption peaks in September, and that in IID peaks in July, both later in the summer. This WRA matches the profile of IID more closely than that of SDG&E.

Figure 36: East San Diego WRA Profile With SDG&E and IID Consumption



Source: California Energy Commission, Supply Analysis and Demand Analysis Offices

CHAPTER 6: Energy Purchases

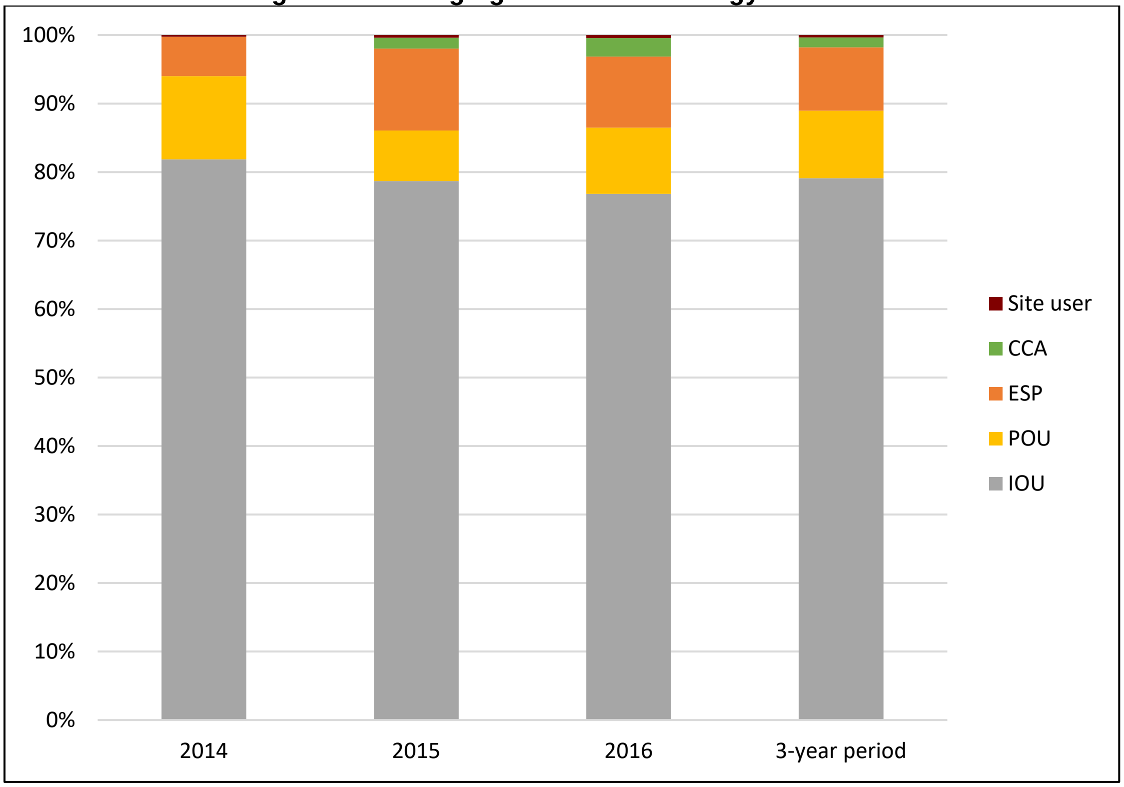
In addition to wind generation data, the California Energy Commission collects data on wind energy purchases from in-state projects. Energy purchasers are required to report data to meet a regulation distinct from that applied to generation operators. Parties who report purchases of energy include public and private organizations, including utilities, energy service providers (ESP), and site users. However, staff makes basic information on generation projects available to purchasers to assist them in reporting accurately. Most purchasers do not generate energy, although there are a few who participate in the market in both roles.

Electricity totaling 36.9 TWh was reported purchased from in-state projects from 2014 through 2016. This electricity consisted of 12.7 TWh in 2014, 11.2 TWh in 2015, and 13.0 TWh in 2016. Over the three-year period, nearly 80 percent of the energy was purchased by IOUs, with smaller fractions by publicly owned utilities (POU), ESPs, and community choice aggregators (CCA). On-site users and CCAs each purchased less than 2 percent of the energy. CCAs started purchasing wind energy in 2015.

From 2014 through 2016, reported wind energy purchases were less than reported net generation by 1.9 TWh or 5 percent, perhaps due to a couple reasons. In some cases, the purchasing party contracted to purchase a mixture of renewable energy, with the percentages determined by the seller. The purchaser did not always know the specific type of green energy it received. Human error could also affect the reports. Generation operators and energy purchasers are not required by law to coordinate their data reports.

The shares purchased by IOUs and POUs decreased over time. In contrast, the shares by ESPs, CCAs, and site users increased. These trends are shown in **Figure 37.** Site users and CCAs were relatively small parts of the total energy purchases, but those parts grew over the period.

Figure 37: Changing Mix of Wind Energy Purchasers

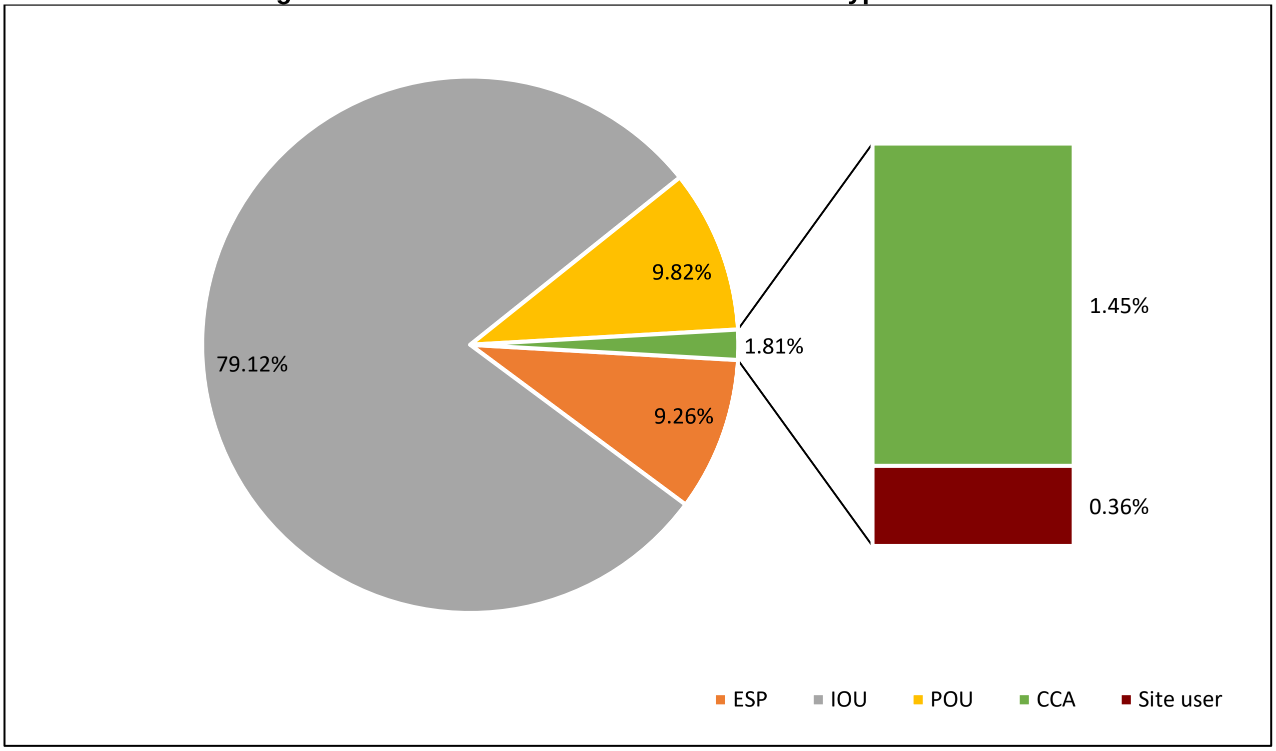


Source: WPRS data set of the California Energy Commission

Figure 38 depicts a breakout of the smaller energy purchases. The graph shows the smallest shares by the CCAs and site users, along with the predominant share by the IOUs.

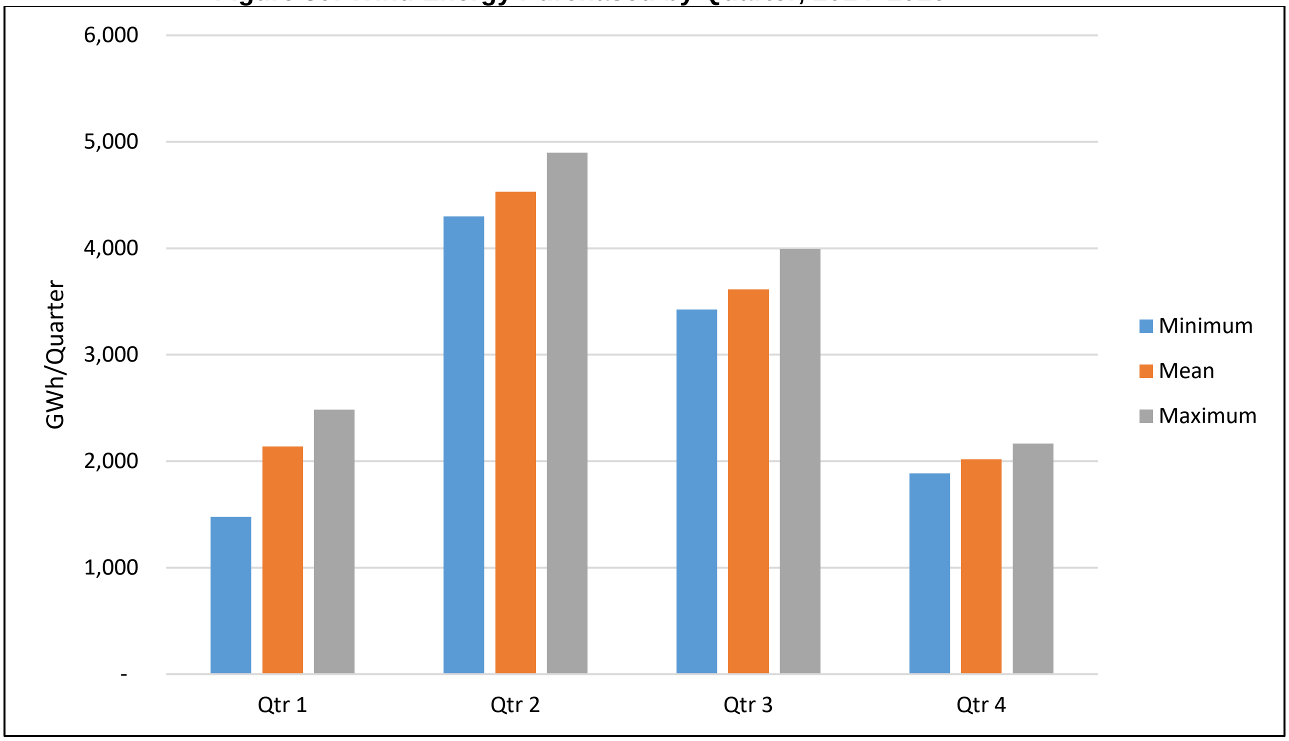
Energy purchases by quarter parallel the generation over a year, with the largest amount in the second quarter. Purchases in the first and fourth quarters are lower, and the variability is highest in the first quarter. **Figure 39** shows the amount purchased by quarter over the period. The values are influenced by the low wind conditions in 2015.

Figure 38: Breakout of the Smaller Purchaser Types



Source: WPRS data set of the California Energy Commission

Figure 39: Wind Energy Purchased by Quarter, 2014–2016



Source: WPRS data set of the California Energy Commission

CHAPTER 7: Conclusions

Statewide Generation and Characteristics

Wind generators in California produced almost 13,000 GWh annually during 2014 through 2016. This amount was enough energy to supply almost two million households in the state. At the end of 2016, there was more than 5,600 MW capacity available to generate. Total capacity was essentially stable over the period. In-state wind generation comprised 7 percent of electric energy generated and 7 percent of capacity in the state in 2016. Production peaked in the second or third calendar quarter of each year.

Statewide CFs for all projects ranged from 24 to 27 percent annually, which included the full range of project vintages and sizes. The CF in 2016 fell in the middle of other in-state electricity sources, being higher than the CF of natural gas and lower than that of small hydropower. The combined capacity factors are lower than would be expected for individual new wind projects, which are larger, benefit from economy of scale, and use modern technology. Larger turbines typically have more effective control systems that can optimize energy production.

The number of turbines decreased to 7,400 and the average capacity per turbine increased from 0.5 MW to 0.8 MW. There was a decrease in the number of turbines in the 0-to-500-kW class and an increase in the 3,000-to-3,500-kW class. By the number of turbines, the smallest size class still made up the largest group of all the size classes.

Capacity factors by quarter for the full period peaked in Quarter 2 at 37 percent and were lowest in Quarter 4 at 17 percent. For the total of the large projects, CF reached 42 percent in June and was at 11 percent in January. These factors include turbines that were available but had restricted operating hours as required by counties or the grid operator.

Capacity factors are cyclical through a year. Variation in CF from year to year was from 36 to 40 percent annually in Quarter 2 and from 29 to 33 percent in Quarter 3. Individual project CFs range more widely, up to a maximum 56 percent annually. Over the full three-year period, the highest individual project CF was 48 percent. During specific months, some projects attain almost 80 percent. These variations exemplify the great variety in operating projects across the state. Both man-made and natural factors contribute to net CF. Small projects exhibit a wide spread in CF, with the spread narrowing in larger projects.

Median project station use energy ranged from 1 to 2 percent of gross production in 2016. It was higher in winter months, when gross production was lower.

At the end of 2016, the smallest rotors were 154 square meters, and the largest rotors were 9,852 sq. m. These areas corresponded to rotor radii of 7 m and 56 m. Specific power ranged from 187 to 750 W/sq. m. Specific energy ranged from 90 to 1,594 kWh/sq. m in 2016.

Staff also statistically compared CF to turbine capacity and rotor area and found that neither association had a very high correlation. This finding is not surprising given the great range in project ages and equipment vintages. Operational projects range from those on the margin of becoming unprofitable to those with current technology and many years of life remaining.

The composition of wind projects and the turbine fleet, and the operators and owners, change continually in an active market of project ownership. Among the top operating companies at the end of 2016 by share of total capacity, NRG Energy, Inc. was the leader, followed by EDF Renewable Energy; Terra-Gen, LLC; and Avangrid Renewables, LLC.

A recent trend is the installation of a single or pairs of commercial turbines at sites of business energy consumers, such as commercial or industrial firms. These projects are structured to supply part of the energy consumed at the site. Four projects like this began during the period.

Wind Speed Resources From 2014 Through 2016

Wind speed is a primary factor in turbine energy production. It may be considered the fuel that drives the wind generator. Higher wind speeds usually lead to higher electrical generation. Wind speeds in 2015 were below average in much of the state, but they were above average over most of the state in 2016. The lower CF in 2015 compared to 2014 or 2016 can be explained largely by the variation in wind speeds in those years. Similarly, the higher CF in 2016 is explained largely by the higher-than-average wind speeds that year. Although other factors contribute to the electricity yield, the fact that the actual generation and speeds confirm one another indicates the high quality of the generation data set.

Regional Generation

California's climates have differing wind regimes and wind speed distributions. Wind generators in different parts of the state show different productivity and profiles. In order of capacity, the wind resource areas are Tehachapi, Solano, San Gorgonio, East San Diego, Altamont, and Pacheco. Tehachapi had the largest capacity at 3,282 MW and produced the largest share of energy at 57 percent of the total. Altamont and Solano generation peaked in Quarter 3, and San Gorgonio, Tehachapi, and San Diego peaked in Quarter 2. Altamont had the highest CFs over most of the year.

Notable changes over the period were:

- A decrease in capacity at Altamont.
- A decrease in number of projects at Altamont and San Gorgonio.

- A decrease in number of turbines at Altamont and San Gorgonio.
- An increase in capacity per project at Altamont.
- An increase in capacity per turbine at Altamont.
- An increase in specific energy at San Gorgonio.

California wind plants are in transition, as the retirement of older turbines lays the groundwork for repowering. As well as in WRAs, projects exist in newer areas, such as a large project in Shasta County and small projects from Tehama to San Bernardino Counties. Future growth may see expansion into lower-wind regions of the state. Successful project design is based on site-specific analysis of wind power available.

Consumption Compared to Generation

Electricity demand in California depends on seasonal temperature cycles, which make the profile of generation important. California statewide wind generation peaks in June and is lowest in January. Electricity consumption peaks in August and reaches the low point in February. The wind generation peak thus occurs two months before the consumption peak, and wind generation is lowest one month before the consumption low.

The timing of consumption and generation varies by WRA and utility. In PG&E, consumption peaks in July. Generation at Altamont peaks in May and at Solano in July, making Solano a closer match. In SCE, consumption peaks in August. Generation at San Gorgonio peaks in May and at Tehachapi in June, making Tehachapi fit closer. In SDG&E, consumption peaks in September, and in the Imperial Irrigation District, it peaks in July. The East San Diego WRA peaks in May, closer to the IID peak.

Wind Energy Purchases

The Energy Commission also collects wind energy purchases data from in-state plants. Purchasing parties can be POUs, IOUs, ESPs, CCAs, or on-site users. The largest share of purchases in 2016 was by IOUs, with almost 80 percent. POUs purchased 10 percent and ESPs 9 percent. The mix of energy purchases changed over time. Site users and CCAs purchased larger amounts, and IOUs purchased smaller amounts. The second quarter saw the largest amounts purchased, with the first or fourth quarter the lowest amounts, depending on the year.

Final Observations

Wind energy generation during 2014 through 2016 contributed significantly to state energy goals. Electricity generated supported the Renewables Portfolio Standard, helped reduce greenhouse gas emissions, and provided economic activity and employment in locations across nearly the length of the state from Shasta to Imperial Counties and from coastal to inland sites. As state energy goals call for increasing shares of total generation to come from renewable sources, policy makers and others will continue to need complete, reliable information on the status of wind energy generation and energy purchases.

This report is a primary source of information and is based on data from the generator operators and parties who purchase energy. It provides an understanding of the wind energy situation in the state for the three-year period of 2014 through 2016. It follows a previous report of the Energy Commission that provided a more comprehensive look for 2014. Wind energy data used in preparing this report has been made public by the Energy Commission.

ACRONYMS AND ABBREVIATIONS

ACRONYM	TERMS AND DEFINITIONS
2016 IEPR Update	*2016 Integrated Energy Policy Report Update*
2017 IEPR	*2017 Integrated Energy Policy Report*
AWEA	American Wind Energy Association
CCA	community choice aggregator: a program that allows a local government to procure power on behalf of the residents, businesses, and municipal accounts from an alternative supplier and receive transmission and distribution service from the existing utility provider.
CF	capacity factor: the ratio of the energy produced to what could have been produced.
COE	cost of energy: the cost to produce a unit of energy.
CPUC	California Public Utilities Commission
CWEA	California Wind Energy Association
ESP	energy service provider: an energy entity that provides service to a retail or end-use customer.
GW/GWh	gigawatt/gigawatt-hour
IOU	investor-owned utility: a privately-owned electric utility whose stock is publicly traded. It is rate regulated and authorized to achieve an allowed rate of return.
kW/kWh	kilowatt/kilowatt-hour
LSE	load-serving entity: a company that secures energy and transmission service to serve the electrical demand and energy requirements of its end-use customers.
m	meter
MW/MWh	megawatt/megawatt-hour
POU	publicly owned utility: a utility operated by a municipality.
QF	qualifying facility: a cogenerator, small power producer, or non- utility generator that has been certified by or self-certified with the Federal Energy Regulatory Commission as meeting certain

	ownership, operating and efficiency criteria.
Sq. m or m^2	square meter
TWh	terawatt-hour: 1,000 gigawatt-hours
W	watt: a unit of electric power.
WPRS	Wind Performance Reporting System: the system of collecting wind energy data mandated by the California Code of Regulations.
WRA	wind resource area: one of the particular areas in California containing a concentration of wind generation projects.

References

American Wind Energy Association (AWEA), 2016a. Market Database Pro database, accessed multiple dates.

AWS Truepower, 2017. *2014, 2015, and 2016, Annual Wind Anomaly Map for California,* unpublished maps prepared for California Energy Commission, Supply Analysis Office, November 2017.

Bailey, B. 2006. California Energy Commission. *California Wind Energy Resource Modeling and Measurement: Measurement Program Final Report*. Publication Number CEC-500-2006-066.

Brower, M. December 9, 2015. "The North American 'Wind Drought': Is It the New Normal?" Web page, https://www.awstruepower.com/the-north-american-wind-drought/

California Energy Commission. 2018. "Electric Generation Capacity & Energy." Accessed January 24, 2018. http://www.energy.ca.gov/almanac/electricity_data/electric_generation_capacity.html.

Energy Information Administration. 2018. *Annual Energy Outlook 2018*. U.S. Energy Information Administration. Publication Number: AEO2018.

California Wind Energy Association (CWEA). 2017. "Comments of the California Wind Energy Association on Proposed Reference System Plan and Related Commission Policy Actions." California Public Utilities Commission, Rulemaking 16-02-007, October 26, 2017.

Christenson, C., 2014. Personal communication, February 20, 2014.

Financial Times. January 23, 2017. "UK Wind Farm Costs Fall Almost a Third in 4 Years." London.

Gasch, R. and J. Twele, 2002. *Wind Power Plants: Fundamentals, Design, Construction and Operation*. Solarpraxis AG, Berlin.

Hingtgen, J., et al. 2017. *Wind Energy in California: 2014 Description, Analysis, and Context.* California Energy Commission, Publication Number: CEC-200-2017-001.

International Electrotechnical Commission (IEC), 2005a. Wind Turbines – Part 2-1: Power Performance Measurements of Electricity Producing Wind Turbines, 2005-12, first edition.

Jacobson et al., 2014. "A Roadmap for Repowering California for All Purposes With Wind, Water, and Sunlight." *Energy* 73 (875-889).

Manwell, J. F., J. G. McGowan, and Anthony L. Rogers. 2009. *Wind Energy Explained: Theory, Design and Application,* second edition. Wiley.

Nelson, Vaughn. 2009. *Wind Energy: Renewable Energy and the Environment.* Boca Raton: CRC Press.

Patel, Mukund R. 2006. *Wind and Solar Power Systems: Design, Analysis, and Operation.* Boca Raton, FL: Taylor & Francis.

Sayigh, Ali. 2012. *Comprehensive Renewable Energy*. Amsterdam: Elsevier.

Simon, Rich, 2016. Personal communication, August 8, 2016.

TrueWind Solutions, LLC, Michael Brower. 2002. "New Wind Energy Resource Maps. Wind Data Set and Revisions Prepared for the Energy Commission in Studies Dated November 2002. Contract Number 500- 01-009. Publication Number 500-02-055F.

Wind-turbine-models, 2016. http://en.wind-turbine-models.com/accessed on multiple dates.

APPENDIX A:
Wind Turbine Groups

Plant Name	Group ID	Manufacturer	Model	Number of Turbines	Rotor (m2)	Turbine Capacity (kW)	Rated Speed (m/s)	Group Capacity (MW)
85A	Remote 2	Vestas	V-17	157	227	90	15.0	14.1
85B	Remote 1	Vestas	V-17	235	227	90	15.0	21.2
Alta I Wind Energy Center	AW1	General Electric	GE 1.5 SLE	100	4,657	1,500	15.0	150.0
Alta II Wind Energy Center	AW2	Vestas	V-90	50	6,362	3,000	18.0	150.0
Alta III Wind Energy Center	AW3	Vestas	V-90	50	6,362	3,000	18.0	150.0
Alta IV Wind Energy Center	AW4	Vestas	V-90	34	6,362	3,000	18.0	102.0
Alta V Wind Energy Center	AW5	Vestas	V-90	56	6,362	3,000	18.0	168.0
Alta Wind VIII, LLC	VE250 to VE299	Vestas	V-90	50	6,362	3,000	18.0	150.0
Alta X Wind Energy Center	AW10	General Electric	GE 2.85	48	8,332	2,850	15.0	136.8
Alta XI Wind Energy Center	AW11	General Electric	GE 2.85	7	8,332	2,850	15.0	20.0
Alta XI Wind Energy Center	AW11	General Electric	GE 1.7	41	8,012	1,700	11.0	69.7
Altech III	Altwind Sub	Micon	65	53	177	65	14.0	3.4
Altech III	Altwind Sub	Micon	108	201	293	108	14.0	21.7

Plant Name	Group ID	Manufacturer	Model	Number of Turbines	Rotor (m2)	Turbine Capacity (kW)	Rated Speed (m/s)	Group Capacity (MW)
Anheuser-Busch	1	General Electric	GE 1.5 SLE	1	4,657	1,500	14.0	1.5
Anheuser-Busch #2	1	General Electric	GE 1.85	1	5,345	1,600	10.0	1.6
Buena Vista Energy LLC	Buena Vista	Mitsubishi	MWT-1000	38	2,960	1,000	13.0	38.0
Cabazon Wind	WT	RRB	600	1	2,209	600	4.0	0.6
Cabazon Wind	WT	ZOND	Z-750	51	2,304	750	5.0	38.3
Cabazon Wind Partners, LLC	All	Vestas	V-47	62	1,735	660	15.0	40.9
Cameron Ridge	Micon 108	Micon	108	34	281	108	16.0	3.7
Cameron Ridge	Micon 700	Micon	700	80	660	700	19.0	56.0
Cemex BMQ	GE 1.5 SLE	General Electric	GE 1.5 SLE	2	4,657	1,500	14.0	3.0
Cemex Madison	1	General Electric	GE 1.5 SLE	1	4,657	1,000	10.0	1.0
Cemex River Plant	1	General Electric	GE 1.62 SLE	2	5,346	1,620	12.0	3.2
City of Soledad	1	General Electric	GE 1.85 SLE	1	5,345	1,000	10.0	1.0
Coram California Development, L.P.	WTG01 to WTG34	Vestas	V-90	34	6,362	3,000	18.0	102.0
Coram Energy LLC	BT 3	General Electric	GE 1.5 SLE	10	4,657	1,500	14.0	15.0
Coram Tehachapi LP	BT 4	Vestas	V-27	29	573	225	16.0	6.5
Diablo Wind LLC	Vesta V-47	Vestas	V-47	31	1,735	580	17.0	18.0

Plant Name	Group ID	Manufacturer	Model	Number of Turbines	Rotor (m2)	Turbine Capacity (kW)	Rated Speed (m/s)	Group Capacity (MW)
Difwind Farms LTD I	All	Micon	108	67	293	108	14.0	7.2
Difwind Farms LTD II	All	Micon	65	36	201	65	15.0	2.3
Difwind Farms LTD II	All	Micon	108	28	293	108	14.0	3.0
Difwind Farms LTD V	All	Micon	108	107	293	108	18.9	11.6
Difwind Farms LTD VI	All	Micon	108	209	293	108	18.9	22.6
Dillon Wind	All	Mitsubishi	MWT-1000	45	2,690	1,000	13.0	45.0
Dutch Energy Wind Farm	Dutch	NedWind	NedWind 40	19	1,256	500	14.0	9.5
East Winds Project	All	NEG Micon	M1500-600	5	1,452	600	15.0	3.0
EDF Renewable Windfarm V Inc.	Kenetech	Kenetech	86-100	65	229	100	13.5	6.5
EDF Renewable Windfarm V Inc.	GE	General Electric	GE 1.5 SLE	6	4,657	1,500	14.5	9.0
Edom Hills Project 1, LLC	Edom 1-8	Clipper	Liberty C93	8	6,793	2,500	14.0	20.0
EUIPH Wind Farm	Bonus 250	Bonus	250	1	531	1,000	15.0	1.0
EUIPH Wind Farm	Nordtank 150	Nordtank	150	9	200	150	15.0	1.4
EUIPH Wind Farm	Micon 108	Micon	105	22	246	108	15.0	2.4
EUIPH Wind Farm	Bonus 65	Bonus	65	59	181	65	15.0	3.8
EUIPH Wind Farm	Bonus 120	Bonus	120	64	246	120	15.0	7.7

Plant Name	Group ID	Manufacturer	Model	Number of Turbines	Rotor (m2)	Turbine Capacity (kW)	Rated Speed (m/s)	Group Capacity (MW)
EUIPH Wind Farm	Nordex 1000	Nordex	1000	10	2,122	1,000	14.0	10.0
FPL Energy Montezuma Winds LLC	1	Siemens	SWT-2.3-93	16	6,789	2,300	13.0	36.8
Garnet Wind Energy Center	Garnet	NedWind	NedWind 40	13	1,256	500	14.0	6.5
Golden Acorn Casino	1	General Electric	GE 1.85 SLE	1	5,345	1,000	10.0	1.0
Golden Hills	1	General Electric	GE 1.79	48	7,450	1,790	14.0	85.9
Green Power I	WT	RRB	600	2	2,209	600	4.0	1.2
Green Power I	WT	ZOND	Z-750	20	1,963	750	5.0	15.0
Hatchet Ridge Wind, LLC	HRW	Siemens	SWT-2.3-93	44	6,797	2,300	12.0	101.2
High Winds	All	Vestas	V-80	90	5,024	1,800	12.0	162.0
IEUA	1	Mitsubishi	MWT-1000	1	2,961	1,000	13.0	1.0
International Turbine Research Inc.	601	Nordtank	NTK500/41	1	1,325	575	15.0	0.6
International Turbine Research Inc.	501-510	Nordtank	NTK65	10	216	75	15.0	0.8
International Turbine Research Inc.	901	NEG Micon	NM900	1	2,140	900	17.0	0.9
International Turbine Research Inc.	401-404	Wincon	W200	4	452	240	15.0	1.0
International Turbine Research Inc.	301-315	Nordtank	NTK65	15	216	75	15.0	1.1
International Turbine Research Inc.	316-337	Vestas	V-17	20	227	90	15.0	1.8

Plant Name	Group ID	Manufacturer	Model	Number of Turbines	Rotor (m2)	Turbine Capacity (kW)	Rated Speed (m/s)	Group Capacity (MW)
International Turbine Research Inc.	101-120	Vestas	V-17E	20	278	110	14.0	2.2
International Turbine Research Inc.	201-296	Wincon	W108	92	301	110	15.0	10.1
Karen Avenue Wind Farm	V39s	Vestas	V-39	6	1,195	450	13.4	2.7
Karen Avenue Wind Farm	GE1.5s	General Electric	GE 1.5	6	3,904	1,500	12.5	9.0
Kumeyaay Wind Farm	Kumeyaay	Gamesa	G87	25	5,945	2,000	17.0	50.0
Manzana Wind	All	General Electric	GE 1.5 SLE	126	4,657	1,500	14.0	189.0
Mesa Wind Power Corporation	30 WTGs	Vestas	V-15	460	177	65	16.0	29.9
Mogul Energy	All	Mitsubishi	MWT-500	8	1,257	500	14.0	4.0
Mojave 16, 17, 18	MHI 600	Mitsubishi	MWT-600	28	1,590	600	16.0	16.8
Mojave 16, 17, 18	MHI 250	Mitsubishi	250	267	616	250	14.0	66.8
Mojave 3	WT	Mitsubishi	250	94	616	250	14.0	23.5
Mojave 4	WT	Mitsubishi	250	116	616	250	14.0	29.0
Mojave 5	WT	Mitsubishi	250	90	616	250	14.0	22.5
Montezuma Wind II	1	Siemens	SWT-2.3-93	34	6,789	2,300	13.0	78.2
Mountain View I	MWT-600	Mitsubishi	MWT-600	74	1,590	600	13.0	44.4
Mountain View II	74-01	Mitsubishi	MWT-600	37	1,590	600	13.0	22.2

Plant Name	Group ID	Manufacturer	Model	Number of Turbines	Rotor (m2)	Turbine Capacity (kW)	Rated Speed (m/s)	Group Capacity (MW)
Mountain View III	All	Vestas	V-47	34	1,735	660	16.0	22.4
Mountain View IV	A01	Mitsubishi	MWT-1000	49	2,960	1,000	12.5	49.0
Mustang Hills LLC	6319	Vestas	V-90	50	6,362	3,000	16.0	150.0
Nestle Waters	1	General Electric	GE 1.62 SLE	2	5,346	1,620	12.0	3.2
North Sky River, LLC	WT	General Electric	GE 1.62 XLE SLE	100	7,854	1,620	10.0	162.0
Oak Creek Wind Power	Phase 2C	NEG Micon	NM1500	1	4,072	1,500	16.0	1.5
Oak Creek Wind Power	Phase 2AB	NEG Micon	NM900	3	2,124	900	16.0	2.7
Oak Creek Wind Power	Phase 1	NEG Micon	M1500-600	7	1,452	600	16.0	4.2
Oak Creek Wind Power	Phase 2	NEG Micon	NM700	33	1,820	700	16.0	23.1
Oasis Power Partners, LLC	All	Mitsubishi	MHI 1000	60	2,552	1,000	13.5	60.0
Ocotillo Express LLC	OWE	Siemens	SWT-2.3-108	112	9,144	2,370	11.0	265.4
Pacific Wind Project, LLC	All	REpower	MM92	70	6,720	2,050	11.2	143.5
Painted Hills Wind Developers	V-15	Vestas	V-15	65	165	65	10.0	4.2
Painted Hills Wind Developers	V-17	Vestas	V-17	166	254	90	10.0	14.9
Phoenix Wind	All	NEG Micon	NM700	3	1,521	700	16.0	2.1
Pine Tree Wind Power Plant	GE 1.5 Cable E	General Electric	GE 1.5 SLE	12	4,657	1,500	14.0	18.0

Plant Name	Group ID	Manufacturer	Model	Number of Turbines	Rotor (m2)	Turbine Capacity (kW)	Rated Speed (m/s)	Group Capacity (MW)
Pine Tree Wind Power Plant	GE 1.5 Cable C	General Electric	GE 1.5 SLE	14	4,657	1,500	14.0	21.0
Pine Tree Wind Power Plant	GE 1.5 Cable A	General Electric	GE 1.5 SLE	16	4,657	1,500	14.0	24.0
Pine Tree Wind Power Plant	GE 1.5 Cable B	General Electric	GE 1.5 SLE	16	4,657	1,500	14.0	24.0
Pine Tree Wind Power Plant	GE 1.5 Cable D	General Electric	GE 1.5 SLE	16	4,657	1,500	14.0	24.0
Pine Tree Wind Power Plant	GE 1.5 Cable F	General Electric	GE 1.5 SLE	16	4,657	1,500	14.0	24.0
Pinyon Pines Winds I	PPI	Vestas	V-90	56	6,362	3,000	18.0	168.0
Pinyon Pines Winds II	PPII	Vestas	V-90	44	6,362	3,000	18.0	132.0
Ridgetop Energy	Micon 108	Micon	108	12	281	108	16.0	1.3
Ridgetop Energy	Vestas V-47	Vestas	V-47	3	1,735	660	17.0	2.0
Ridgetop Energy	Nordtank 75	Nordtank	75	163	154	75	18.0	12.2
Ridgetop Energy	Vestas V-39	Vestas	V-39	26	1,195	500	16.0	13.0
Ridgetop Energy II	Vestas V-47	Vestas	V-47	71	1,735	660	17.0	46.9
Rising Tree Wind Farm I	Rising Tree I	Vestas	V-112	24	9,852	3,300	15.0	79.2
Rising Tree Wind Farms II	Rising Tree II	Vestas	V-112	6	9,852	3,300	15.0	19.8
Rising Tree Wind Farms III	RT III	Vestas	V-112	30	9,852	3,300	15.0	99.0
Robertsons Ready-Mix	GE 1.5 SLE	General Electric	GE 1.5 SLE	2	4,657	1,000	10.0	2.0

Plant Name	Group ID	Manufacturer	Model	Number of Turbines	Rotor (m2)	Turbine Capacity (kW)	Rated Speed (m/s)	Group Capacity (MW)
Safeway Tracy	1	Mitsubishi	MWT-1000	2	2,961	1,000	13.0	2.0
San Gorgonio Farms Wind Farm	Bonus 65s	Bonus Siemens	B65	20	201	65	14.8	1.3
San Gorgonio Farms Wind Farm	V90s	Vestas	V-90	2	6,362	3,000	15.0	6.0
San Gorgonio Farms Wind Farm	Bonus 120s	Bonus Siemens	B120	55	284	120	12.5	6.6
San Gorgonio Farms Wind Farm	V39s	Vestas	V-39	15	1,195	500	13.4	7.5
San Gorgonio Farms Wind Farm	V42s	Vestas	V-42	19	1,385	500	12.0	9.5
San Gorgonio Westwinds II	M700-Windustries	Micon	700	14	1,810	700	19.0	9.8
San Gorgonio Westwinds II	Micon 700	Micon	700	48	1,521	700	19.0	33.6
San Gorgonio Wind	WT	General Electric	GE 1.5 SLE	33	4,778	1,500	10.0	49.5
Shiloh I Wind	All	General Electric	GE 1.5 SLE	100	4,657	1,500	14.0	150.0
Shiloh III Wind Project, LLC	All	REpower	MM92	50	6,720	2,050	11.2	102.5
Shiloh IV Wind Project, LLC	All	REpower	MM92	50	6,720	2,050	11.2	102.5
Shiloh Wind Project 2, LLC	All	REpower	MM92	75	6,720	2,050	11.2	153.8
Sky River Partnership	WT	Vestas	V-27	314	573	225	25.0	70.7
Solano Wind 1,2	misc.	Vestas	V-47	23	1,735	660	15.0	15.2
Solano Wind 1,2	misc.	Vestas	V-90	29	6,362	3,000	17.0	87.0

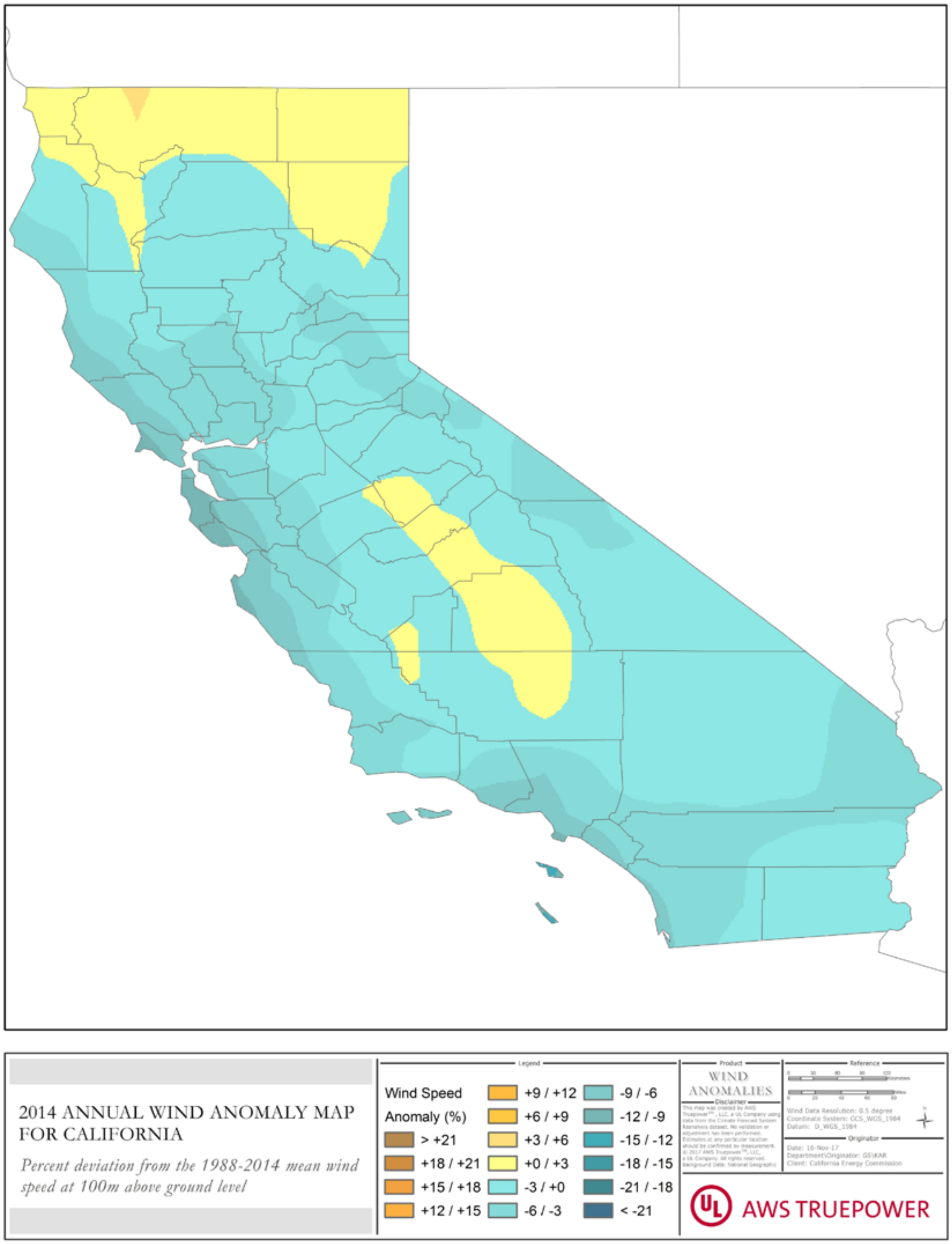
Plant Name	Group ID	Manufacturer	Model	Number of Turbines	Rotor (m2)	Turbine Capacity (kW)	Rated Speed (m/s)	Group Capacity (MW)
Solano Wind 3	misc.	Vestas	V-90	31	6,362	1,800	12.0	55.8
Solano Wind 3	misc.	Vestas	V-90	24	6,362	3,000	17.0	72.0
Superior Farms	1	Mitsubishi	MWT-1000	1	2,961	1,000	13.0	1.0
Taylor Farms	1	General Electric	GE 1.85 SLE	1	5,345	1,000	10.0	1.0
Teichert Vernalis	1	General Electric	GE 1.5 SLE	1	4,657	1,500	14.0	1.5
Terra-Gen 251 Wind	Vestas V-15	Vestas	V-15	4	177	65	18.0	0.3
Terra-Gen 251 Wind	Vestas V-17	Vestas	V-17	185	227	90	18.0	16.7
Terra-Gen Mojave Windfarms	DW 160	Danwind	23A	68	415	160	13.0	10.9
Terra-Gen Mojave Windfarms	MHI 600	Mitsubishi	MWT-600	29	1,590	600	16.0	17.4
Terra-Gen VG Wind	V47	Vestas	V-47	1	1,735	660	18.0	0.7
Terra-Gen VG Wind	Z750	ZOND	Z-750	9	1,963	750	12.0	6.8
Vasco Wind Energy Center	1	Siemens	SWT-2.3-101	34	8,007	2,300	13.0	78.2
Victory Gardens IV	Vestas V-47	Vestas	V-47	1	1,735	660	17.0	0.7
Victory Gardens IV	Vestas V-27	Vestas	V-27	89	573	225	14.0	20.0
WAGNER WIND, LLC	Wagner	Vestas	V-90	2	6,362	3,000	16.0	6.0
Wal-Mart Red Bluff	1	General Electric	GE 1.5 SLE	1	4,657	1,000	10.0	1.0

Plant Name	Group ID	Manufacturer	Model	Number of Turbines	Rotor (m2)	Turbine Capacity (kW)	Rated Speed (m/s)	Group Capacity (MW)
Whitewater Hill Partners, LLC	All	General Electric	GE 1.5	41	3,317	1,500	15.0	61.5
Wind Resource I	Nordtank 1-134	Nordtank	NTK 65-13	134	201	65	15.0	8.7
Wind Resource II	Vestas 1-13	Vestas	V-47	13	1,735	660	16.0	8.6
Wind Resource II	Bonus 1-175	Bonus	B65	175	201	65	15.0	11.4
Wind Stream Operations 6039	V16	Vestas	V-16	1	177	70	12.5	0.1
Wind Stream Operations 6039	660	Vestas	V-47	1	1,662	660	12.5	0.7
Wind Stream Operations 6039	V15s	Vestas	V-15	17	177	65	12.5	1.1
Wind Stream Operations 6039	750s	ZOND	Z-750	6	1,662	750	12.5	4.5
Wind Stream Operations 6040	V17	Vestas	V-17	1	227	90	13.0	0.1
Wind Stream Operations 6040	750s	ZOND	Z-48	2	1,810	750	13.0	1.5
Wind Stream Operations 6040	V15s	Vestas	V-15	78	177	65	13.0	5.1
Wind Stream Operations 6041	V17	Vestas	V-17	3	177	90	12.5	0.3
Wind Stream Operations 6041	750s	ZOND	Z-750	2	1,662	750	12.5	1.5
Wind Stream Operations 6041	V15	Vestas	V-15	42	177	65	12.5	2.7
Wind Stream Operations 6042	Z550	ZOND	Z-550	1	1,452	550	12.5	0.6
Wind Stream Operations 6042	GE 1.5	General Electric	GE 1.5	1	3,848	1,500	12.5	1.5

Plant Name	Group ID	Manufacturer	Model	Number of Turbines	Rotor (m2)	Turbine Capacity (kW)	Rated Speed (m/s)	Group Capacity (MW)
Wind Stream Operations 6042	V15	Vestas	V-15	30	177	65	12.5	2.0
Wind Stream Operations 6042	V17	Vestas	V-17	26	227	90	12.5	2.3
Wind Stream Operations 6111	V15	Vestas	V-15	39	177	65	13.0	2.5
Wind Stream Operations 6111	V17	Vestas	V-17	42	227	90	13.0	3.8
Windland Inc. Boxcar I	V-25	Vestas	V-25	2	490	200	8.0	0.4
Windland Inc. Boxcar I	V-39	Vestas	V-39	1	962	500	8.0	0.5
Windland Inc. Boxcar I	Bonus	Bonus	120	9	283	120	8.0	1.1
Windland Inc. Boxcar I	V-27	Vestas	V-27	11	572	225	8.0	2.5
Windland Inc. Boxcar I	AAER	AAER	1500	2	4,654	1,500	8.0	3.0
Windland Inc. Boxcar II	V-47	Vestas	V-47	1	1,734	660	8.0	0.7
Windland Inc. Boxcar II	V-27	Vestas	V-27	14	572	225	8.0	3.2
Windland Inc. Boxcar II	V-25	Vestas	V-25	20	490	200	8.0	4.0
Windstar Energy, LLC	23 WTGs	Gamesa	G87	23	5,945	2,000	16.0	46.0
Windstar Energy, LLC	37 WTGs	Gamesa	G80	37	5,027	2,000	17.0	74.0
Wintec Energy #2-A	8001-8002	Vestas	V-47	2	1,735	660	15.0	1.3
Wintec Energy, Ltd.	Wintec Palm	Renewtech	Renewtech 99KW	22	314	99	15.0	2.2

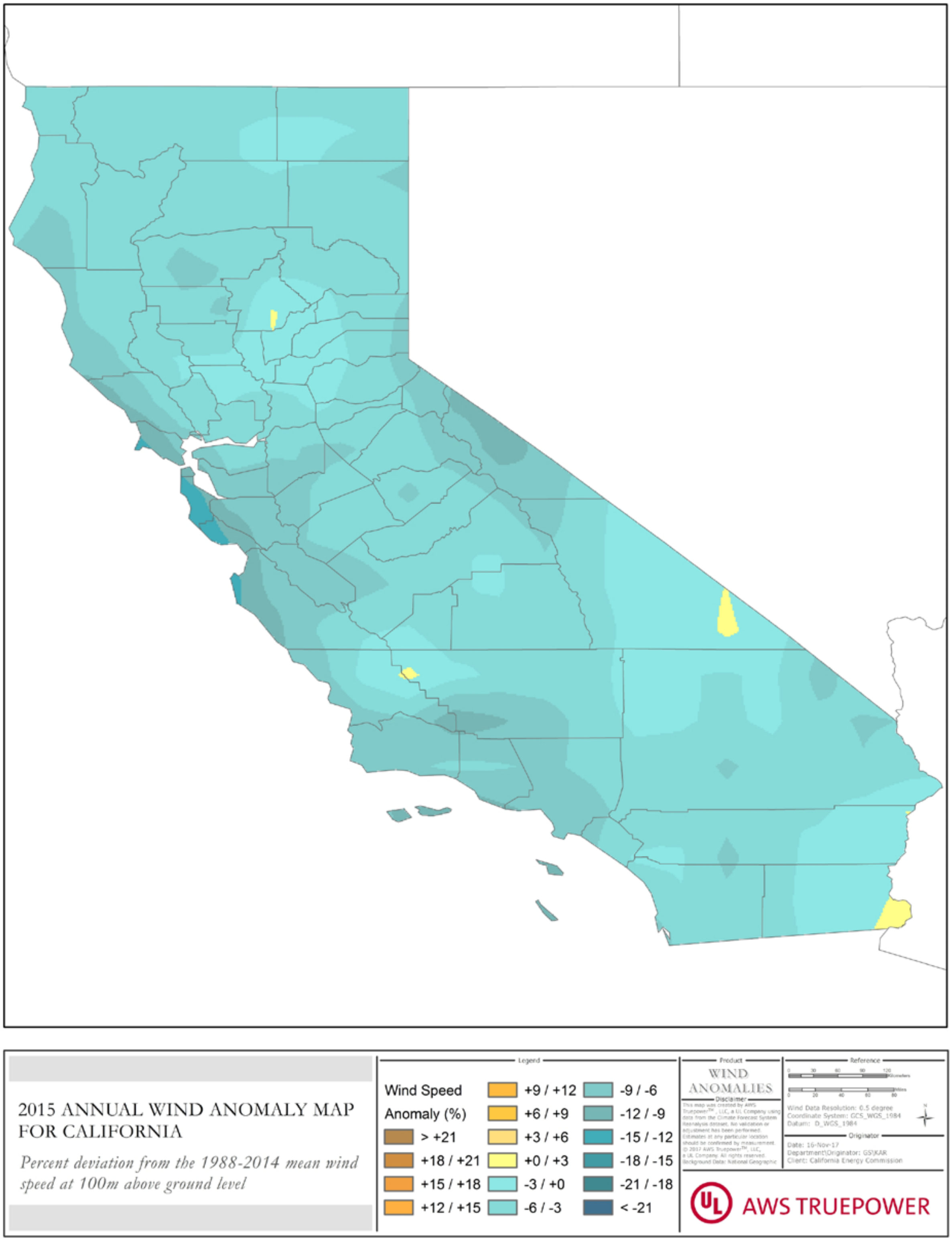
APPENDIX B: Annual Wind Speed Variations

Figure B-1: Wind Speed Deviations From Average in 2014



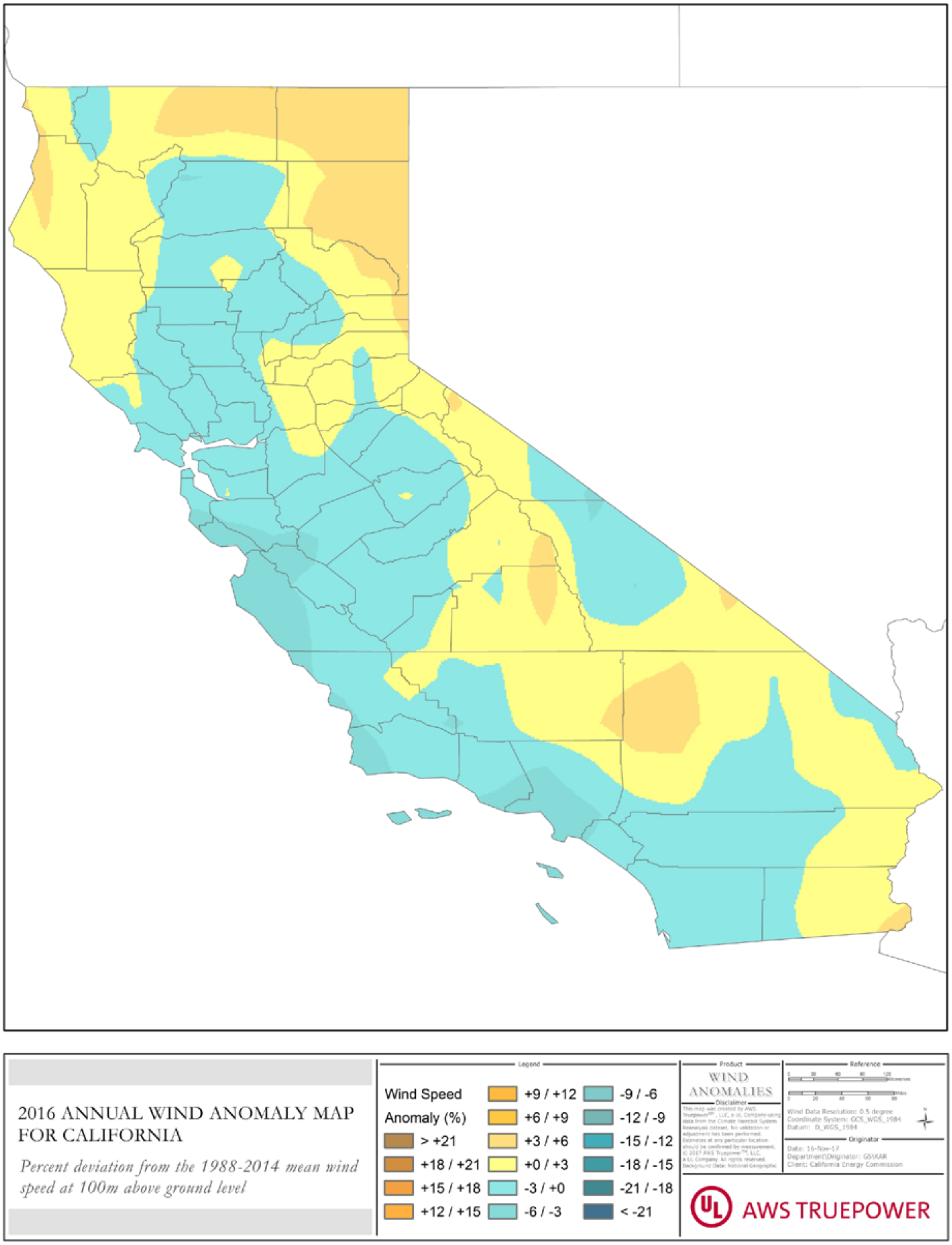
Source: AWS Truepower

Figure B-2: Wind Speed Deviations From Average in 2015



Source: AWS Truepower

Figure B-3: Wind Speed Deviations From Average in 2016



Source: AWS Truepower